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MAN INVESTIGATES THE PLANETS

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16. Abstract

Contemporary scientific concepts about the origin of the Earth and the planets of our Solar System are discussed in this book. The satellites of the planets, the minor planets, meteoric objects, bolides, and meteorites are described. The question of why spacecraft are used to study the Sun, its accompanying planets and their satellites is also explained.

This book contains data about the surface and atmosphere of Mars and Venus and about the seasons, days, and climate of these planets.

This book contains much of interest about space technology. Data are given for the contemporary cosmodromes and spacecraft centers, spaceflight devices for various purposes, and the chemical, nuclear, and electrical rocket motors; the selection of interplanetary trajectories and the peculiarities and conditions for flight to the near and distant celestial objects of our Solar System both by automatic unmanned devices and by manned spaceships are also discussed. The book is designed for a wide circle of readers.

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ANNOTATION

Reviewer: Candidate of Technical Sciences A. T. Mitin.

Editor: Candidate of Technical Sciences A. F. Erich.

"Provide in the new Five-Year Plan... execution of scientific research in space for the purpose of the development of long-range telephone-telegraph communication, television, meteorological prediction and the study of natural resources, geographical investigations, and the solution of other national economy problems with the help of satellites, automatic and manned devices, and also the continuation of fundamental scientific investigations of the Moon and the planets of the Solar System...."

From the "Directive of the Twenty-Fourth Congress of the Communist Party of the Soviet Union with respect to the Five-Year Plan of Development of the National Economy of the USSR for the 1971-1975 period".

MAN INVESTIGATES THE PLANETS

N. A. Varvarov

CHAPTER 1. PLANETS IN THE SERVICE OF THE EARTH

There is no doubt that today one can find few people who could ask: are the gigantic efforts of the massive army of scientists, engineers, and highly qualified specialists who produce the meteorological, navigational, geodesic, radio, television, and other Earth satellites justified? Here, as they say, the issue is clear. Because today Earth satellites have already successfully solved the most complex problems of scientific and national economic significance. And there is no doubt that the circle of these problems will always continue to expand. /5*

But undoubtedly the answer to another question is of interest to many people today: what will the investigation and conquest of celestial objects do for people?

It has been known for a long time that truth is found through comparison. Thus it follows that an important cause of our at present insufficient knowledge of our own planet is in the fact that scientists cannot compare it with another celestial object which they would investigate just as they do the Earth. Investigating only one celestial object, they are not in a position to distinguish the regular and general from the particular and individual. At the present time there is still no definite answer to the question of the origin of the planets and the development of the Solar System. There is even a lot about the internal life of our own spaceship, the Earth, which still remains unclear to us. Investigators have more or less thoroughly studied the Earth's crust, and it consists of only about one-thousandth of our planet's radius in all! But why does the Earth consist of shells of different density? How does one explain why the thickness of the Earth's crust in a continent is five times greater than under the oceans? Why is there no granitic layer under the oceans, while it is universally part of the makeup of the continental crust? Of what internal processes are earthquakes and volcanism the symptoms? We are still able to formulate only theories as to the causes of the motions of the Earth's crust, tectonic activity, uplift of a molten mass to the surface, and the formation of /6 the continents and oceans. Much remains unknown about the question of the origin of the Earth and also about the history of the air and water envelopes which surround our terrestrial sphere. Contemporary Earth science is still not in a position to give a clear and valid enough answer to these and other questions.

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*Numbers in the margin indicate foreign pagination.

The solution of the problem associated with the processes which are going on inside the Earth and which appear to be the causes of tectonic activity, earthquakes, and volcanism requires, of course, the penetration of scientific instrumentation into the Earth's interior. But this is a problem of exceptional complexity. It has immediately become completely evident that the comparative study of the Earth and other planets, chiefly those which are located near the Earth and which are similar in this or that respect to it with regard to their basic physical properties, can contribute a great deal to the elucidation of processes within the Earth. One is speaking first of all about Venus and Mars and also about the Earth's natural satellite, the Moon.

The Earth and the Planets

The comparative study of the planets from the geophysical point of view is of enormous interest because scientists believe that all the planets of the Solar System were formed as a result of condensation from one and the same protoplanetary dust cloud, and their subsequent development should basically have been subjected to unique laws. Thus, for example, one may suppose that being composed of material which was radioactive, all the planets should undergo a heating-up stage after their formation. The Soviet scientist Academician A. P. Vinogradov considers that, under the influence of radioactive decay in the interiors of all the planets, there should occur a gradual melting out of the lighter material, which rises to the surface while the heavier material sinks towards the planet's center. It is probable that precisely in this way the relatively light terrestrial crust was formed on the terrestrial sphere, while the deeper interior of the Earth consists of heavier material. Gases and water vapor are liberated from the planet's depths in the course of the radioactive melting of the light materials. One should think that the Earth's initial atmosphere and its oceans were formed in precisely this manner. The buoyancy of the melted "bubbles" of light material caused an uplift of the planet's surface which could lead to the formation of mountains and to volcanic eruptions. However, very significant differences undoubtedly arise in the course of specific processes occurring on various planets both on the surface and in their interiors. They are produced by a multitude of factors, but notably by differences in the mass and the physico-chemical composition of the planets, by the presence or absence of an atmosphere on them, its composition and density, the temperature conditions, and also by the presence or absence on them of plant or animal life, its level and nature of development, and a number of other circumstances. If this hypothesis is valid, then we must suppose that the /7 differences in the deep rocks on various planets will only be of a quantitative nature. But if we discover on other planets qualitatively different rocks, then this discovery will be testimony to the fact that our planetary system was probably formed by means of the capture of clouds of cosmic dust which differed in their physico-chemical composition. In this respect the investigation of the asteroid belt, the minor planets, which are distributed between the orbits of Mars and Jupiter, is of special interest. Some scientists consider that the asteroids are part of a disrupted planet, to which they have given the name Phaeton. They assign to this catastrophe a date of 75 million years ago. Other scientists hold to another theory, namely, that the asteroids are the intermediate structures from which the planets are formed. If this theory is true, a comparison of asteroid samples with soil from the Earth, the Moon, and in the future from the terrestrial planets, Mars, Venus, and Mercury, may be the key to unlocking the secrets of the origin of the Solar System. The possibility offered by space technology to become acquainted with the condition of other worlds where many processes occur in a different thermodynamic and physico-chemical environment permits a deeper understanding of the processes which occurred on the Earth in different stages of its evolution. Therefore a comparison of our planet with other worlds of the Solar System permits us to estimate more exactly the current cosmogonical, cosmological, geophysical, biological, geological, and other ideas concerning the origin, evolution, and internal structure of our planet. This knowledge will facilitate a deeper understanding of the regularities of the formation and distribution of useful terrestrial minerals and, consequently, the improvement of geological predictions, which are so important to mankind.

According to our contemporary notions, the Earth consists of a number of shells, geospheres[1], which are distinguished from one another both with respect to the composition of the material of which they are formed and with respect to their physical properties. The Earth's crust consists of a sedimentary layer (about 30 km on the average), below which is situated a shell, or the Earth's mantle, which extends to a depth of the order of 3,000 km. Still deeper one finds the liquid inner core of the Earth, within which there occurs a smaller and, according to geophysicists, a solid subcore. If one compares our planet, for example, with an apple, then the thickness of the investigated surface layer is significantly thinner than the skin with respect to the entire apple.

Man has always penetrated deeper and deeper into the Earth's interior in his searches for useful minerals. But this course of action requires that colossal difficulties be overcome. Each new meter into the depths of the subterranean storeroom is gained today with enormous effort. Therefore our mines /8
and drill holes are not deep in comparison with the Earth's radius. The deepest of them do not exceed 8 km. But this is not very much on the scale of the terrestrial sphere. The thickness of the Earth's crust is 2 - 3 times greater. Regardless of the fact that the upper layer of the mantle lies at a comparatively shallow depth (10-15 kilometers from the Earth's surface in some places, and somewhat less under the oceans), it is not a very simple matter to reach it. Scientists are now seeking ways to penetrate to it. Diverse projects are being pursued: one envisions super-deep drilling of the Earth's crust with the help of a plasma, and others suggest the use of automatic depth rocket devices of the so-called "subterranean mole" type.

It is assumed at the present time that the Earth's crust was formed along with the hydrosphere and the atmosphere by the melting and uplifting of the

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[1]The concentric spherical shells into which our planet is subdivided are called geospheres: the atmosphere (gaseous envelope), the hydrosphere (the totality of all the Earth's water, there in solid, liquid, and gaseous form), the lithosphere (solid surface), and the biosphere. The latter includes part of the atmosphere, hydrosphere, and lithosphere. There are no sharp boundaries between these shells; they overlap one another.

more fusible components of the material of the upper mantle. Volcanic activity apparently was the continuation of this process, as a result of which lava, cinders, water vapor, and gases come to the Earth's surface from the upper mantle.

Why is it very important to know what the mantle of our planet consists of? Some useful minerals which we are extracting today, for example, iron ore, have various kinds of impurities which lower their high-grade composition. Sometimes they occur in the ore at a level even greater than 50%. And why? Scientists suggest that we are now extracting ore which is found in the so-called state of fusion. This means that pure ore located at great depth in a layer of the mantle is in a liquid melted state under the influence of heating by radioactive heat. Breaking through under pressure to the surface, the melt cuts through mineral layers of different composition composing the Earth's crust, and because of this circumstance is "dirtied up" by them. The same thing probably occurs with other useful minerals which are also located at significant depth. If this is so, then having penetrated through to the Earth's mantle, it will be possible to extract from it many useful minerals in a pure form without any kind of admixtures. But before reaching the mantle, it is necessary to breach the considerable thickness of the sedimentary rocks of the Earth's crust!

There will evidently not be any of these sedimentary rocks on the Moon and perhaps on Mars and some other celestial objects; therefore their surface layer is probably similar in its physico-chemical and mineralogical composition to the upper layer of the Earth's mantle. This is why the investigation of their surface layers acquires enormous practical significance.

Earthquakes and Planetquakes

Earthquakes have since time immemorial aroused horror among people as the cause of enormous damage. According to UNESCO data, our planet is shaken by subterranean shocks about one and one-half million times a year. Several times /9 a year they cause catastrophes, at times even turning entire cities into heaps of ruins. It has been calculated that during the last one hundred years about one million persons have perished from earthquakes. During several strong earthquakes the human fatalities were exceedingly great. Thus, for example, the earthquake in Japan on September 1, 1923, became literally a national disaster. The cities of Tokyo and Yokohama were completely destroyed. In Sagami Bay raging waves over ten meters in height rushed up onto the shore, spreading death and destruction. About 100 thousand persons perished, and the number of injured was far greater. About a million people were left homeless.

Thousands of people died as a result of the severe earthquakes which occurred in Chile in May of 1960, in Yugoslavia in July of 1963, and in Alaska in March of 1964. In January of 1973 the capital city Managua of Nicaragua was almost completely destroyed; about ten thousand people died. According to the data of a special UN committee, 14,000 people perish each year on the average over the entire Earth from earthquakes.

Might it be possible to predict this terrible spontaneous disaster and at the same time decrease in some way its consequences? At present it seems impossible to do this, since the seismic centers are concealed very deeply. The nearest of them are located at a depth of approximately 10 km, but the majority of them occur at depths of 20-40 km. Geophysicists assume that earthquakes are associated primarily with the continuing process of differentiation of deep material, and since it occurs at depths within our planet inaccessible to man, success has not yet been achieved in establishing the regularities of this phenomenon. One should note that everything that occurs at great depths is in one way or another reflected in the Earth's upper layers, similar to the way in which a person's inner state is reflected on his face and in his behavior.

Having penetrated hundreds of millions of kilometers into space, man has examined closely the depths of his own planet only down to several thousands of meters. As Academician A. Sadovskiy says, "The ways of penetrating into the Earth's depths are so difficult that it may prove to be easier to obtain data about their structure from a comparison of the Earth's properties with the results of observations of the properties of other objects in the Solar System." If one proceeds from the assumption that identical causes produce similar effects, the pressing necessity for studying planetquakes on celestial objects becomes completely evident.

Volcanism on Celestial Objects

About 600 volcanoes exhibiting activity have been counted on the Earth at the present time. It has been established that eruptions of many of these volcanoes have occurred during the course of several recent centuries. 418 volcanoes comprise the "ring of fire"; they are located on the shores of the Pacific Ocean. Submarine volcanoes are incomparably larger. The geologist G. B. Udinpsev writes that there are as many of them on the bottom of the Pacific Ocean as can be indicated on a map consistent with its scale. Volcanoes may be /10
dormant and then reawaken. They have brought and will bring incalculable disasters to people. It is sufficient to point out that the City of Pompeii is buried under the ashes of the volcano Vesuvius. A gigantic explosion on August 27, 1883, which was the result of an eruption of the volcano Krakatoa, led to the destruction of a large part of an island and killed more than 40,000 people. The total amount of ash, pumice, and slag ejected during the eruption of the volcano Temboro (1815) on the island of Mumbawa is estimated to be 200-300 km^3. The roar of the enormous explosions was heard at a distance of 2,000 km. There was total darkness within a radius of 800 km. The ash layer was 60 cm thick at a distance of 160 km from the site of the eruption, and approximately 20 cm thick at a distance of 400 km.

The layers of volcanic ash, pumice, and slag discovered while drilling into the Earth's depths indicates that, during remote periods in the Earth's history, volcanic areas occupied a significant portion of the Earth and achieved far greater strength than at the present time. But today people still do not know the causes of volcanic activity, and as a result they cannot successfully contend with these recalcitrant and terrible forces of nature. Scientists assume that the drop in the surface temperature of our planet and its glaciation are probably associated with volcanic activity in the past. As a result of volcanic activity, the atmosphere has been dirtied up by ash particles, and a thick cloud cover has been formed; this situation has resulted in a decrease of the atmosphere's transparency to the Sun's thermal radiation. Because of this circumstance the average temperature of our planet's surface has decreased, and this has facilitated an increase in the snow and ice cover of this or the other hemisphere of the Earth. Its boundary has reached not only to the temperate latitudes but has descended still lower towards the equatorial zone.

If it also follows from the assumption that identical causes produce identical effects, the pressing necessity for studying volcanic activity on celestial objects becomes completely evident. Actually, if it were established that a periodic temperature drop has occurred on Venus or Mars just as on Earth, and the snow and ice cover on part of their surface has increased, and if the degree of volcanic activity were also determined, then it would be possible with greater probability than today to assume that the glaciation on the Earth had this phenomenon as its cause. The scientists also assume that mountains are the effect of the ejection of colossal masses of gas and molten rocks from within the planet's solid crust. The formation of gigantic cavities beneath the planetary crust should have resulted in its settling and wrinkling, i.e., in the origination of mountain chains and gigantic fractures, faults several kilometers deep stretching for thousands of kilometers.

Up until recently the majority of selenologists believed that the Moon is a dead celestial object in which any kind of internal processes are absent. However, not only did the Soviet scientist N. A. Kozyrev observe on November 3, 1958 an eruption of gases in the crater Alphonsus, but American scientists /11
discovered, on October 23, 1959, three volcanic eruptions in the crater Aristarchus. Evidently volcanic activity on the Moon occurs, and the Moon is not a "dead" world; it probably "lives" a complex internal life at the present time. A number of scientists believe that the Moon's surface preserves traces of immense processes which cannot possibly assigned to meteoric impacts. The phenomena of mountain-building and the relief of the Lunar surface may give an indication of the nature and scales of the volcanic processes which have taken place in the Moon's history. A detailed geomorphological investigation of the peculiarities of Lunar relief will permit drawing a definitive conclusion as to the causes which gave rise to it.

Observations of flashes on Mars and very sound conclusions in favor of the manifestation of active volcanism on this planet even at the present time are well known. Thus the Japanese scientist Ts. Sakheki described four cases (1937, 1951, 1954) when he or his coworker observed luminous points on Mars. In the first two cases a light flash was observed for 5 minutes, and in the latter case it lasted about 5 seconds in all. Sakheki explains these phenomena as being volcanic eruptions.

Yellow clouds on the planet's disk and a general turbidity of its atmosphere which have been repeatedly observed, especially distinctly visible during periods of the great oppositions of Mars (1956 and 1971) have naturally been associated with the ejection of ash particles during volcanic eruptions, since the assumption of "dust storms" does not withstand its critics because of the significantly greater vacuum of the Marsian atmosphere compared with that of the Earth and because of the smaller intensity of the Sun's action.

The abundance of carbon dioxide gas in Venus' atmosphere and its significant dust content point to a high level of volcanic activity. Venus' high temperature, measured both by radiotelescopes and with the help of the inner planetary spacecraft of the Venera series confirms this conclusion.

...One must assume that at such a high temperature on the planet's surface, as the American scientists point out, Venus' interior consists of a molten mass, and its crust has a very insignificant density. This means that there exist all the necessary conditions for volcanic activity.... The adherents of this hypothesis argue as follows: if Venus' surface is actually so hot and, if volcanic eruptions are unavoidable, here we have a ready-made explanation of why the cloud cover around Venus is so dense. The hypothesis seems plausible, and a matter for the future is whether or not it will be confirmed or refuted.

Volcanic activity on Jupiter is well-known from visual and photographic observations. The manifestation of powerful volcanic processes on this planet was directly observed during the period 1961-1968 when the equatorial zone was covered by a belt of ash particles. Powerful radio emission bursts also confirm the existence of centers of volcanic activity on the planet's solid surface.

The astronomers Barnard, Danjon, Lyot, and others have noted many details /12
and changes on the surface of the large satellites of Jupiter and Saturn which could indicate volcanic activity.

Investigations of the nature of volcanic activity on celestial objects will undoubtedly help explain not only the mechanism and sources of terrestrial volcanism but will also bring us closer to unlocking the secret of the formation of mountains and useful minerals and also to explaining the causes of the glaciation of our planet at various stages in its evolution.

The Secret of "Space Winters" on the Earth

The periods of climatic oscillations revealed by geologists exhibit in many cases significant coincidences with the periodicity of space phenomena established by astronomers. In the first place, one encounters the rather well--studied periodic variations in the intensity of solar radiation. Its influence can probably explain not only minor climatic rhythms — in particular, the 11-12 year periods long familiar to many geologists and paleontologists, but also to a certain extent the climatic cycles of significantly larger duration. The nature of the very extended periods of climatic oscillations such as the ice ages, which were measured in thousands of years, is not completely clear.

Scientists assume that periods of glaciation of our planet were caused either by intense volcanic activity, which resulted in dustiness of the atmosphere, due to which less Solar heat reached the Earth, or they were caused by space phenomena. It has been established by astronomical investigators that the Solar System moves in the galaxy at a rather high speed, amounting to 247 km/sec at the present time. The Soviet scientist P. P. Parenago (1952) has calculated and constructed an approximate orbit of the Sun. He showed that the Sun is revolving around the galaxy's central masses according to laws similar to

Kepler's laws of planetary motion, i.e., almost along an elliptical orbit. The time between two successive passages through perigalacticon or apogalacticon, which he denoted as the anomalistic period of the Sun's motion, amounts to 176×10^6 years[2]. Thus the linear speed amounts to 250 km/sec at perigalacticon and 207 km/sec at apogalacticon.

It is completely possible that the Sun and its planetary retinue have encountered several times in certain regions of our galaxy enormous accumulations of cold, dusty material. This circumstance would result in a periodic decrease in the Sun's brightness, and consequently would result in a decrease in the amount of solar heat reaching the Earth, which would cause a sharp cooling of its surface. The scientists assume that this circumstance has occurred several times: 3.2 billion years ago, 2.6-2.2 billion years ago, and /13 most recently 1.2 billion years ago.

Investigating the condition of the climate on other celestial objects will make it possible to find out from the Earth this secret of its period. Actually, if it should be established that periodic coolings have occurred on celestial objects of the Solar System at the same times as on the Earth, it would be possible to assume with greater probability than today that the ice ages on the Earth were produced by space factors.

The Past and Future of the Earth

If one assumes that the Sun was hotter in the distant past than [illegible]sent, the most distant planets Pluto and Neptune would evidently have had [illegible] suitable temperature for the development of life. The Earth's surfa[illegible]s at this time probably incandescent to a degree excluding any possibility of the development of life on it. But as the Sun's brightness weakened, the planets Uranus, then Saturn, and later Jupiter, Mars, and finally the Earth, would have been in a more favorable temperature situation. Thus, together with the fading of the Sun, a shift in the habitability of the planets from the most distant to those which were situated closer to the Sun probably occurred. One must assume that, if this hypothesis is valid, then a visit to Mars by people will establish what awaits our Earth in the future, and, having landed on Venus, man will find out what our planet was like in the distant past. But if one proceeds on the assumption that the Sun was colder in the very distant past, then immediately the entire process of the shift in habitability of the planets would have had to proceed in the reverse order, namely: from the planets located nearer to the Sun to those more distant from it. In this case, having visited Mars, people will find out about the past Earth, and Venus will tell about its future. Thus, it is entirely possible that explorations of Mars and Venus will allow the Earth's evolution to be established, and also find out if our Sun is heating up or cooling off.

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[2]The period of a complete revolution amounts to approximately 200 million years according to the data of the well-known Soviet astrophysicist V. A. Ambartsumyan.

There is no doubt that these scientific discoveries of the highest importance permit making wider cosmogonical and cosmological generalizations. They extend our knowledge about the structure, composition, and evolution of the Earth and the entire Solar System.

The Moon, Venus, Mars, and Terrestrial Life

The problem of the presence of life forms on other celestial objects is of great interest. Although this problem has already occupied scientists for a long time, only now is the possibility emerging, however, to cross over from speculative discussions to specific investigations. Each thinking person poses himself the question: is mankind the only civilization in the Universe or do other life forms or other civilizations similar to the terrestrial one exist beyond the boundaries our our planet? Certainty of the multiplicity of inhabited /14 worlds, which has been advanced by many scientists already during the last few centuries, is deeply rooted in the minds of mankind. Ordinarily, when authors touch on the question of the existence of life on this or that celestial body, they begin to analyze the conditions which prevail it and prove, on the basis of this, whether life is possible or impossible on it...

The solution of the problem of life in the Universe, — as Academician A. I. Oparin validly remarks, — lies not only in whether or not one can imagine if living beings can or cannot live on a particular celestial body under the conditions now existing on it but rather whether one can establish if this complicated form of material activity which we call life could have arisen and developed on this body in the process of its evolution. Every celestial body and, in particular, every planet evolves in the course of its existence, and those conditions which we find on it now are far from eternal. There could arise at a specific stage of a planet's existence conditions on it favorable for the origin of life, which then would gradually adapt to the changing conditions...

Here it is appropriate to emphasize that the problem of extraterrestrial life forms was of interest to Vladimir Il'ich Lenin. He proved that there is life on the planets of the Solar System and in other worlds of the Universe, and living beings inhabit them. The artist Aleksandr Evel'evich Magaram[3] has told us about this.

...."It was the end of August 1916," we read in Magaram's memoirs. "One day I was walking with Lenin in Montre, where Lunacharskiy lived at the time... We boarded the passenger ski ship which plied Lake Geneva... The sky was inexpressibly solemn against the dark velvet background of which the stars were brightly shining." They began to speak about the stars, about religious myths, and about the infinity of what exists. The artist advanced several not completely successful opinions (as he now recalls with a smile). Lenin softly and patiently corrected him.

— "Well, what about life? — I asked. — And life under the corresponding conditions has always existed — Lenin answered. — It is entirely possible that

[3]Memoirs; see the journal *Nauka i Zhizn'*, No. 4, p. 59, 1960.

life exists on the planets of the Solar System and in other places in the Universe, and rational beings live there. It is possible that, depending on the gravitational force of a particular planet, its specific atmosphere, and other conditions, these rational creatures experience the external world through other senses which differ significantly from our senses... Notice: — Lenin continued, — they have assumed until recently that life is impossible in the depths of the ocean, where the water presses with enormous force. Now it has been established that different kinds of fish and many other diverse living things have adapted to life on the bottom of the oceans. They replace the tactile organs by a single eye, and others illuminate their path by organic luminescent /15 eyes. As you see, life exists even in such conditions under which it would seem impossible to us. Much is still unknown to us here, and it is possible to know thoroughly its nature only by dialectical means... — Lenin concluded."

These remarks of Vladimir Il'ich are of exceptional interest for us.

It is necessary to assume that, because of the different conditions on the planets, the adaptation of living matter to them has turned out differently than on the Earth. Therefore, a comparison of the life forms discovered in space with terrestrial life will make it possible to qualify the nature of its evolution in the Universe. And this will permit either confirming the uniqueness of the laws of evolution of living matter or introducing necessary corrections to the established opinions of the greatest secret of nature — the origin of life and conditions for its evolution on our planet. It is entirely possible that such living organisms which will seem exceedingly useful on Earth may be discovered on the Moon, Mars, Venus, or on other planets and their satellites.

At the present time many micro-organisms are already widely used in various technological processes. Thus bacteria convert grape juice into wine, transform milk into an acidophile, and produce healing penicillin. It is difficult to imagine what useful transformations micro-organisms of Mars, Venus, and other celestial bodies will produce for us. It is unquestionable that the natural conditions on Mars, for example, are significantly more severe than on Earth, and perhaps cultured Martian plants will permit us to convert our terrestrial tundras into fruitful fields?!

Biology and medicine receive new unprecedented possibilities. In this respect the Moon, the planets, and the satellites may become dependable scientific bases for the solution of many problems associated with the vital activity of the plant and animal worlds.

We will take as an example the interaction of living organisms with a factor of the external environment such as the force of gravity.

It is well-known that the idea of determining the role of gravitational forces in the life of organisms was first advanced by K. E. Tsiolkovskiy in 1925 in his essay "Biology of Dwarfs and Giants". In his opinion the size of organisms is determined by the force of gravity on the surface of the Earth or some other celestial body. If terrestrial life would have developed on the Moon, all living beings would have turned out there 6 times larger, and consequently their brains would have been far larger. And, on the contrary, only dwarfs would live on Jupiter, where the force of gravity is 2.6 times greater than on Earth.

Similar notions have been advanced by other scientists. Thus, D. V. Thomson has contended that the majority of terrestrial forms would be similar to the short-legged digging reptiles in case of an increase in the Earth's attraction, and on the contrary they would become light and thin in case of a decrease in the attractive force by a factor of two, and they would be more active and expend less energy.

It has still not proven successful to confirm the validity of these hypotheses by direct observations of living organisms. However, there is no doubt that on the Moon, under conditions of a strongly weakened gravitational field, on Mars and the other celestial bodies, it will be possible to check this hypothesis. An important part will be played by investigations associated with the effect on the animal and plant world of space radiation, the absence of a noticeable magnetic field on the celestial bodies, or, on the contrary, a considerable magnitude of it. For example, the search for living organisms and the problems of the survival of the terrestrial living substance will enter into the circle of problems considered by biologists and doctors. It is precisely on the Moon, Mars, and the other celestial bodies that man will be able to prepare himself in the biomedical sense for more distant space travels. /16

Space in the Service of the Earth

In the middle of the last century during the observation of the total eclipse of the Sun on August 18, 1868, the French astronomer Janssen observed multicolored lines with the aid of a spectroscope directed at the Sun's edge. Among the variety of lines already known he noticed one new bright-orange line. It could not be emitted by one of the materials well-known at that time. The American astronomer Norman Lockyer was carrying out observations simultaneously with Janssen. He also advanced the idea that there is in the Sun's atmosphere a gas unknown at that time. They called it "helium" (from the Greek "Helios" — the Sun). They began to search for a similar gas on the Earth. In 1881 they discovered it in the gases of the volcano Vesuvius, and in 1905 they separated it from the mineral bearing the designation "Cleveite". This example affirms that one should not exclude the possibility of similar discoveries later on. One must take into consideration the fact that, due to the restriction on the region of the spectrum accessible to investigation from the Earth's surface, elements have been identified in the Sun for only 60% of the cases at the present time. It is completely understood that, based on observations from the Moon, it would be possible not only to identify the remaining chemical elements but also be possible to discover (similar to the case of helium) new elements not known up to the present time.

The outbursts and explosions on the Sun, regardless of the almost three-hundred year duration of their study, starting from the time of Galileo, remain a riddle as before. Scientists assume that the magnetic fields on the Sun play an important role in all the phenomena of Solar activity associated with the motions and outbursts of charged particles. It will be possible, with the help of a special Solar magnetograph, to investigate the magnetic fields of a star This will permit checking the hypothesis of the Soviet astronomer A. B. Severnyy that the Solar flares arise as the result of an unusually rapid compression and disruption of magnetic fields resulting in the impulse heating of a small region of Solar gas to a temperature of the order of 15,000,000°C.

We still do not know what produces the remarkable periodicity in the activity of our daytime star. Now it is quiet, and then fiery hurricanes rage on /17
its surface. It is remarkable that the Sun's activity increases with an increase of the spots on it. But the more data that becomes known about the Solar sunspot cycle, the more mysterious the problem seems. A solution of it is of interest to many specialists. For example, the close dependence of the animal and plant life of our planet on the Sun's activity is not subject to doubt. During the periods of its heightened activity the number of nervous-psychic and cardiovascular illnesses increases, the condition of hypertonics worsens, and an epedemic of grippe engulfs our planet. In 1965 at the seminar "The Sun and the Biosphere" the physicians Yu. V. Aleksandrov and V. N. Yagodinskiy advanced the notion that in 1968 one should anticipate a large grippe epedemic arising in connection with an increase in Solar activity. All those afflicted by grippe in 1968-1969 can confirm this.

The total amount of radiative energy which the Earth receives from the Sun is characterized by a quantity called the Solar constant. But what its value is and within what limits it can vary is still not clear. Meanwhile calculations show that a change in the Solar constant by 1% should result in a change in the average temperature of the atmosphere by approximately 1%. To what extent this is a large change is clear from the following example. The warming recorded on the Earth at the start of our century (particularly noticeable at higher latitudes) was caused by a variation in the mean temperature of the atmosphere by 0.6°C in all, and the cooling which began in the 1950s is associated with a change of the average temperature by 0.3°C in all.

Recent high altitude experiments indicate the possibility of altering the Solar constant by 2-2.5 percent. But it is still not clear what the nature of this phenomenon is.

Observatories of the Soviet Union are conducting continuous observation of the Sun's activity. Information about the smallest of its suspicious variations is quickly communicated to the "Sun-Earth" Scientific Council located at the Institute of Terrestrial Magnetism, the Ionosphere, and Radio Wave Propagation of the USSR Academy of Sciences (IZMIRAN). The data received at the Council is quickly transmitted to Washington, Tokyo, Australia, France, Czechoslovakia, and West Germany. Foreign scientists also communicate information on the Sun's behavior to their own colleagues through their own regional centers. As soon as increased activity is noted on the Sun, a geophysical alarm signal "Alert!" is then sounded in all countries of the world. Upon this signal geophysical rockets are launched from the firing grounds, the dome shutters of observatories are opened, and the telescopes are aimed at the Sun.

It is well-known that practical requirements have exerted a decisive effect on the development of science and technology. Physics, and primarily atomic physics, today represents the forefront edge of human activity. A deep understanding of the elementary particles of high energies and an explanation of the laws which operate in the amazing microworld is the main direction in the solution of the problem of controlled thermonuclear reactions.

What can space give physicists in this regard? Undoubtedly quite a lot. /18
In order to investigate nuclear processes with the help of high energy particles it is necessary first of all to study how to produce them. We obtain high energy particles immediately with the help of special accelerators. They consist of enormous electromagnets with a weight of tens of thousands of tons and with an enormous amount of the most complicated mechanisms.

In our country the most powerful accelerator in the world has been constructed with an energy of 76 billion electron volts. Soviet physicists assume that they will probable succeed in obtaining particles with an energy up to 400 and possibly up to a 1,000 billion electron volts.

And all this regardless of the fact that space attracts the attention of physicists more and more. Why? The point is that in order to achieve a deeper penetration to the atomic nucleus particles are necessary which possess an energy of thousands of billions of electron volts. It will be a long time, evidently, before we succeed in obtaining them on the Earth. They not only occur in outer space, but there we find gigantic thermonuclear reactors — the Sun and the stars — created by nature itself. Vast processes occur in them whose study will give the most valuable information about the properties of matter and energy. It is precisely in these natural laboratories that it will be possible to investigate the behavior of matter under conditions not yet attainable on the Earth: practically an ideal vacuum, gigantic pressures, and very high temperatures. Speaking figuratively, the problem reduces to the fact that, having learned the secret of space thermonuclear processes, how do we set fire to the "Promethean fire" on Earth?

Study of the activity of our daily star has another important scientific and practical significance. It is well-known that the Sun exerts a decisive influence on all biological processes on the Earth, the climatic conditions, the state of the ionosphere, on which the weather and radiocommunications within the Earth's boundaries depend. Here is our planet, "bathing" in the Sun's atmosphere, and tied to it by strong bonds. It reacts sensitively and obediently to each breath of the star. The stormy processes which take place on it are periodically accompanied by gigantic outbursts and the ejection of an enormous mass of matter and energy.

Earlier scientists thought that this is reflected only in the behavior of the needle of a magnetic compass. But then it became clear that the powerful streams of charged particles coming out of the Sun very noticeably influence the operation of radiocommunication equipment and also the climate and the weather. Thus it has been established that the most enormous of all the outbursts on the Sun known to scientists, which occurred February 23, 1956 in an area ten times larger than the entire surface of our planet, was equivalent in its power to the explosion of a million hydrogen bombs. This explosion of colossal force caused a sharp intensification in the flux of particles racing away with enormous speed. The intensity of the space radiation at the Earth increased by a factor of two and one-half. The flux of electrically charged particles which approached the Earth caused a disruption in the magnetic field of our planet. At this time a magnetic storm developed in the atmosphere and, as a result, interruptions developed in the operation of radiocommunication equipment, and many other phenomena were noted. /19

In connection with the development of cosmonautics, whose principal goal is to reach other worlds, the study of the composition of the energy spectra of Solar and cosmic radiation takes on enormous practical significance. This is explained by the fact that such periods arise in the Solar System when, as the result of flares on the Sun, interplanetary space is filled with radiation destructive to living organisms. Particularly intense fluxes of Solar protons have an unfavorable effect on the electronic equipment of spaceships. In addition, the plasma bursts escaping from the Sun and wandering in near-Solar space and having a very high temperature can literally transform any spaceship traveling in interstellar space into steam. Not knowing of these phenomena, it is impossible to produce the means for protection from them, and it is impossible to carry out extended flights of spaceships which have investigators on board. Therefore the investigation of the phenomena in the enormous "laboratory" spread out between the Earth and the planets is not only of a deep scientific-theoretical interest, such as an understanding of the secrets of the transformation of matter, but is also of far reaching practical significance. It has been experimentally proven that there exists in nature an antisubstance called antimatter alongside the substance called matter. The solution of the problem of the antimatter search in the Universe, its accumulation and protection, and ultimately its use, is of exceptional interest to mankind. In the first place, because the antisubstance will have an enormous cognitive significance, since its discovery opens slightly for us the curtain of the other half of the world and at the same time doubles our knowledge of the properties of matter. In the second place, the process of annihilation of matter and antimatter is an ideal energy source from the point of view of efficiency. The "caloricity" of annihilated fuel is approximately a thousand times higher than for nuclear heat, which in its turn is a million times "more calorific" than chemical fuel. Therefore antimatter is the most promising form of fuel for future star flights.

Atmosphereless celestial bodies (the Moon, Mercury, and others) may prove to be of inestimable help in the searches for antimatter. In this regard the proposal of the Soviet scientist N. Vlasov to search for radioactive "spots" on the Moon is a very attractive one. Such spots could arise as the result of the annihilation of small space strangers — meteors consisting of antimatter, upon their encounter with the matter of the Lunar surface. An analogous phenomenon is impossible on the Earth due to the fact that such meteors will be annihilated in the terrestrial atmosphere.

"...Today it will seem highly unlikely to some that it will be possible to transport payloads from other planets, — said the President of the USSR Academy of Sciences Mstislav Vsevolodovich Keldysh in one of his maiden speeches. — But could people really think about regular communications and contemporary freight transfer between various continents in an epic in which the technology of navigation has remained at the level of the pirogue and the raft?...". /20

There is still no necessity to speak now of the imminent crisis in raw materials or the energetic maintenance of economics on the Earth, since there are no bases on which to calculate how large terrestrial reserves and useful minerals are. You see we now know almost nothing about what is stored at great depths in our planet. But, of course, the time will come when our offspring are faced with the problem of developing the industrial reserves of other celestial bodies. One should take into account the fact that differences and conditions have probably facilitated the origin on celestial bodies of minerals which are very rare on the Earth and probably unknown to us in general. Therefore one should not exclude the possibility of the transportation of some extremely necessary minerals from other celestial bodies to the Earth.

These are only some examples which clearly reflect the terrestrial aspect of space accomplishments. They indicate that the objective requirements of science and economics have placed mankind in a position of having to move out into space for the purpose of knowing the celestial bodies.

Until recently almost all of natural science (except astronomy) has concentrated its attention on the study of terrestrial nature, terrestrial objects, phenomena, and processes. Space activities give a new powerful stimulus to the further investigation of fundamental processes and phenomena joining the Earth and the Universe. It is becoming clear that the study of the Universe is a very effective means of solving terrestrial problems. Studying outer space and celestial bodies, science will be guided by knowledge of the Earth and *vice versa*. Such a combination, taken together with a scientifically well-founded manufacture and technology and with practical and multi-faceted applications of knowledge, will result in an unimagined increase in man's power over his material surroundings and in a genuine transformation of our cradle — the Earth.

Today we are on solid ground when we say that a new promising stage is starting in the development of terrestrial science. New areas of the sciences have developed at the junction with astronomy which concern themselves with the solution of the fundamental problems of natural science. These are astrobiology and astrobotany, which study the condition and development of animal and plant life on celestial bodies of the Solar System, astrogeography and astrogeology, which utilize knowledge about the Earth to investigate the celestial bodies, astrophysics and astrochemistry, which reveal the physical conditions and chemical composition of celestial bodies, and bioastroclimatology and space medicine, which investigate the effect of climatic and living conditions on the development of animal and plant life on the planets. Such new areas of knowledge have sprung up as selenophysics (the physics of the Moon), areophysics (the physics of Mars), aphrophysics (the physics of Venus), and other directions in natural science.

Space research will facilitate the final confirmation of the fundamental philosophical position on the unity of the laws of the Universe generally, and including the unity of the laws of evolution of living matter, with the sugges- /21
tion at the same time of an infinite variety of the specific forms of its evolution. The broad prospective which is being opened up by space technology for the solution of the secrets of the celestial bodies cannot fail to disturb

mankind. However one should not forget that subsequent investigations of the Solar System will demand many more scientific searches and a bold flight of the technological imagination. There is no doubt that new discoveries and accomplishments beyond the Earth will exert a significant effect on the evolution of society.

Individual scientific problems solved with the help of space technology will not be directly followed by economic gains. But this does not mean at all that they will not subsequently play an important role in the evolution of human society. The President of the USSR Academy of Sciences M. V. Keldysh has spoken of the fact that we should know about nature and as much about its essence as we can use at a particular moment. Here it is appropriate to refer to Hertz, who discovered radio waves, and Rutherford, who split the atomic nucleus. You see, they also assumed that their discoveries would not be of practical significance for a long time. But it only took a few decades in all for life to prove the reverse.

The history of natural science indicates that there are no useless discoveries. Almost each step on the path of knowledge of the physical world finds this or the other practical application in the end.

In our times, when science is more and more being turned into a direct industrial force, fundamental investigations take on special significance. Applied science is always on view in operation and in application. And that is why its results are visible and tangible. Materializing a theory, it helps in the introduction of new discoveries into production.

Fundamental science has a different meaning: it prepares a qualitatively new jump in the development of industrial forces, making room for scientific-technological progress.

What should one conclude from all that has been said? First of all one should conclude that the investigation and conquest of celestial bodies is not a useless matter — "knowledge begets knowledge". Space research of the planets and on the planets have already given rise to new directions in natural science, moved aside the relative boundaries of mankind's knowledge, and thanks to this produced new possibilities for mankind's penetration into the essence of the processes occurring in the Universe, and at the same time it has already provided today an abrupt acceleration in society's scientific and technological progress.

CHAPTER 2.
FROM MERCURY TO PLUTO

The family of celestial objects which surround our daily star, the Sun, is composed of space objects of different sizes. There are 9 major planets in it, which have in all 32 natural satellites, and there are as well several thousand minor planets, the so-called asteroids. In addition, interplanetary space in all directions is intersected by an enormous number of comets and streams of meteoric material (Figure 1). /22

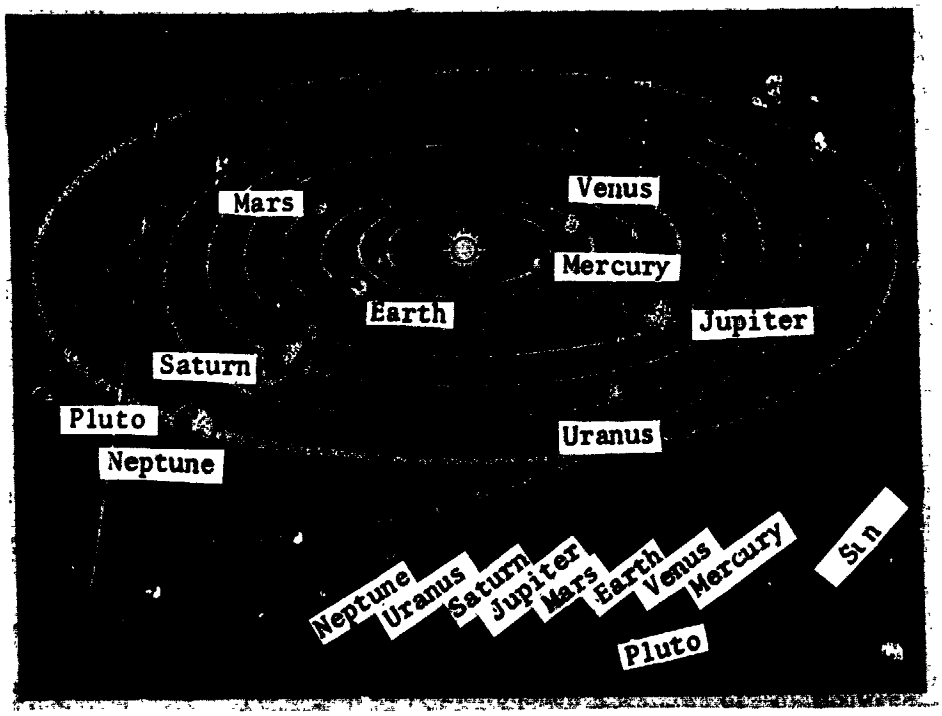

Figure 1. Solar System in a Plan View and the Mutual Inclinations of the Planetary Orbits.

Beginning on October 4, 1957, the day of the launch of the first Soviet artificial Earth satellite in the world, a significant number of spacecraft devices, artificial satellites of the Earth, the Moon, the planets, and the Sun, has been added to the natural celestial objects.

Already in ancient times people noticed among the multitude of stars populating the heavens several stars which continually shifted from one constellation to another, i.e., as if they were wandering. They called them planets (from the Greek word "planao", which in translation means "I wander"). In ancient times people observed five such stars with the unaided eye. They considered them to be mysterious non-deities; therefore the ancient Romans and Greeks assigned to each of them the name of a god or goddess whose heralds they represented in peoples' imagination.

The nearest planet to the Sun, which changes position more rapidly than the others in the heavens and is constantly hidden in the Sun's rays, has received the designation Mercury — in honor of the messenger of the gods and patron of trade and travelers, the god Mercury.

The brightest planet, which exceeds in its brightness all the stars and decorates the heavens with its bluish light at evening and morning twilight, was called Venus — in honor of the goddess of beauty.

The name of one of the gods adored in ancient Rome — Mars, the god of war /23
and military art, was given to the planet having a reddish-orange color resembling the color of blood and the blaze of a fire.

A bright planet, the giant of the Solar System, was named Jupiter in honor of the supreme god.

The dim ash-gray color of the most distant of the planets visible with the unaided eye prompted people to give this gloomy planet the name Saturn — the god of all-absorbing time.

When the telescope was discovered, three more new planets were seen in the sky with its help, and according to tradition they were given names from the ancient Roman and Greek mythology. The planet discovered on March 13, 1781 by the founder of stellar astronomy, William Herschel, was called Uranus, the name of the god personifying the sky. The planet discovered on September 23, 1846 by the German astronomer Galle, which has a dark-blue color with a greenish tint, recalling the color of sea water, was named in honor of the god of the sea, Neptune. But the name of the lord of the underworld — Pluto — was bestowed on the planet discovered on March 13, 1930 by the astronomer Clyde Tombaugh. The first two letters of this planet's name agree with the initial letters of the first and /24
last names of Percival Lowell, who predicted its position in the sky.

It is not without interest to remark that one encounters other names in the literature for the planets, namely: Mercury (Hermes), Venus (Aphrodite), Earth (Gaia), Mars (Ares), Jupiter (Zeus), Saturn (Chronos), Neptune (Poseidon), and Pluto (Hades). The duplicity in the nomenclature of the planets is explained by the fact that the ideological religious basis of the ancient Greeks and Romans was in principle identical, but the names of the gods and goddesses were different. The Latin names are the ones generally used, it is assumed to be correct to use the Greek nomenclature in making up adjectives which contain roots of Greek words. Thus, for example, analogous to a geographical map (the terms consisting of Greek words — "Gaia" — Earth and "grapho" — writing), a map of Mars is called areographic (from the word Ares), a map of the Moon is called selenographic (Selena — the ancient goddess personifying the Moon).

The planets and their satellites are dark objects of a spherical shape which do not shine by their own light. If they seem to us to be bright points, this is because they reflect sunlight. Based on their dimensions, mass, density, chemical composition of the atmospheres, rate of rotation, and other characteristics, they are divided into two groups: the terrestrial planets and the giant planets.

The first group contains: Earth, Mercury, Venus, and Mars, i.e., planets which are closer to the Sun. They have comparatively small sizes (5-13 thousand km in diameter) covered by a crust of solid material. These planets have a high average density (3.9-5.5 g/cm^3). Their atmospheres are negligible with regard to their mass and volume and are very tenuous in comparison with the planet's remaining mass. The atmospheres of Mars and Venus consist primarily of nitrogen and carbon dioxide. All the planets of this group rotate comparatively slowly about their axes. Some characteristics of these planets are given in Table 1.

The giant planets consist of the following: Jupiter, Saturn, Uranus, and Neptune; their dimensions are very large (from 4 to 11 Earth diameters), and their densities are on the contrary very small, 2.5-3 times less than the Earth's density. They rotate very rapidly about their axes; therefore the days on them last from 10 to 15 hours. Because of the centrifugal force generated by such rotation, these planets are flattened at the poles and bulged in the equatorial plane.

The giant planets are located at significantly larger distances from the Sun; therefore their surface temperatures are very low, minus 140°C and lower. These planets are covered by dense atmospheres consisting of heavy gases: methane and ammonia. Hydrogen and its compounds with carbon — methane (CH_4) and with nitrogen — ammonia (NH_3) constitute a significant part of their mass. As one goes deeper into these planets, the gaseous state gradually turns into a liquid condensed state. This occurs at a depth of several hundreds of kilometers. /27
The large masses of these planets and their distinguishing enormous distances permit them to maintain a family of satellites near themselves. First in this regard is the planet Jupiter, which has 12 satellites, and second is Saturn, which has 10 (the last of them was discovered in 1966 by the French astronomer A. Dollfuss). Uranus and Neptune have 5 and 2 satellites, respectively. Some characteristics of the giant planets are given in Table 2.

The most distant planet, Pluto, stands out. It is an exception to the group of outer planets. Its calculated mass and size indicate an improbably high density of matter (50 times greater than the density of water, which, however, cannot be considered as an exactly-established fact). It moves in an elongated orbit which is highly inclined to the plane of the ecliptic; therefore some astronomers have suggested that Pluto may at one time have entered Neptune's system and may possibly have been its satellite, but then some forces or other tore it away from this system.

At the contemporary level of terrestrial telescopic technology the discovery of new planets is a very difficult matter. Searches of the entire sky with a grasp of all objects whose brightness is at the limit even for the most powerful telescope in the world would have required many centuries. You see, the larger a telescope is, the proportionally smaller is the region of the sky it photographs.

TABLE 1. FUNDAMENTAL PROPERTIES OF THE TERRESTRIAL PLANETS AND THEIR ORBITAL ELEMEN

Planet	Distance, Millions of km: From the Sun, Min.	Max.	Avg.	From the Earth, Min.	Max.	Orbital Velocity (Linear), km/sec: At Perihelion	At Aphelion	Avg.	Period of Revolution (Terrestrial Days) Average Value: Sidereal	Synodic	Axial Rotation Period, Days, Hrs., Min.	Gravi Accel at Sur cm/
Mercury	46	69.8	57.9	82	217	58.94	38.83	47.83	87.9	115.88	58 days 16 hrs.	368
Venus	107.5	108.9	108.2	39.0	260	35.24	34.60	35.00	224.7	583.9	243.1 days	[illegible]
Earth	147.1	152.1	149.6	-	-	30.00	29.54	29.76	365.2	-	23 hrs. 56 min. 0.5 sec.	[illegible]
Mars	206.7	249.1	227.9	56.4	401.2	25.56	24.72	24.11	687.0	779.9	24 hrs. 37 min. 23 sec.	3

Planet	Inclination of Planet's Equatorial Plane to its Orbital Plane	Eccentricity	Equatorial Diameter, km	Average Velocity, km/sec: Circular	Escape (Second Cosmic)	Velocity for Flight from Earth	Duration of Transfer Flight (Earth Days): Along an Ellipse	With the Third Cosmic Velocity of 16.67 km/sec	No. of Satellites
Mercury	?	0.205	5000	2.94	4.2-4.3	13.5	105	-	-
Venus	178°	0.007	12106	7.23	10.37	11.5	146	-	-
Earth	23°27'	0.017	12754	7.91	11.19	-	-	-	1
Mars	24°48'	0.093	6620	3.6	5.03	11.6	259	70	2

FOLDOUT FRAME 1

FOLDOUT FRA 2

ERTIES OF THE TERRESTRIAL PLANETS AND THEIR ORBITAL ELEMENTS

rbital Velocity Linear), km/sec			Period of Revolution (Terrestrial Days) Average Value		Axial Rotation Period, Days, Hrs., Min.	Gravitational Acceleration at the Surface, cm/sec^2	Surface Gravity Relative to the Earth's
Perihelion	At Aphelion	Avg.	Sidereal	Synodic			
.94	38.83	47.83	87.9	115.88	58 days 16 hrs.	368-374	0.38
.24	34.60	35.00	224.7	583.9	243.1 days	888	0.90
.00	29.54	29.76	365.2	-	23 hrs. 56 min. 0.5 sec.	981.4	1.0
.56	24.72	24.11	687.0	779.9	24 hrs. 37 min. 23 sec.	388	0.38

Average Velocity, km/sec			Duration of Transfer Flight (Earth Days)		No. of Satellites	Radius of Sphere of Influence, Thousands of km	Radius of Sphere of Attraction, Thousands of km
Circular	Escape (Second Cosmic)	Velocity for Flight from Earth	Along an Ellipse	With the Third Cosmic Velocity of 16.67 km/sec			
2.94	4 2-4.3	13.5	105	-	-	90-136	19-29
7.23	10.37	11.5	146	-	-	612-621	168-171
7.91	11.19	-	-	-	1	913-944	256-265
3.6	5.03	11.6	259	70	2	524-631	117-142

FOLDOUT FRAME 2

TABLE 2. FUNDAMENTAL PROPERTIES OF THE GIANT PLANETS AND THEIR ORBITAL

Planet	Distance, Millions of km					Orbital Velocity, km/sec			Periods of Revolution (Terrestrial Days)		Axial Rota
	From the Sun			From the Earth					Average Value		
	Min.	Max.	Avg.	Min.	Max.	At Perihelion	At Aphelion	Avg.	Sidereal	Synodic	Period
Jupiter	740.7	815.9	778.3	591	965	13.69	12.44	13.05	4332.6	398.8	9 hrs. 50
Saturn	1348.1	1507.9	1426.9	1199	1653	10.18	9.14	9.64	10759.2	378.1	10 hrs. 14
Uranus	2737	3007	2870.9	2586	3153	7.12	6.48	6.80	30687	369.6	10 hrs. 4
Neptune	4459	4537	4498.5	4309	4682	5.47	5.38	5.43	60184	367.5	8-15 hr.
Pluto	4451	7369	5911.7	4309	7527	6.10	3.67	4.81	90700	366.7	?

Planet	Inclination of Planet's Equatorial Plane to its Orbital Plane	Eccentricity	Equatorial Diameter, km	Average Velocity, km/sec			Duration of Transfer Flight (Earth Days)	
				Circular	Escape (Second Cosmic)	Minimal Velocity for Flight from the Earth	Along an Ellipse	With the T Cosmic Vel of 16.7 km
Jupiter	3°07'	0.048	139.76	42.55	60.4	14.2	2 yrs. 267 days	1 yr. 39
Saturn	26°45'	0.056	116700	25.66	36.4	15.2	6 yrs. 18 days	2 yrs. 1
Uranus	98°00'	0.047	51000	15.07	20.8	15.9	16 yrs. 14 days	6 yrs. 28
Neptune	29°	0.008	50000	16.57	23.7	16.2	30 yrs. 225 days	12 yrs. 3
Pluto	?	0.247	-	7.43	~15	16.3	45 yrs. 119 days	19 yrs. 9

PROPERTIES OF THE GIANT PLANETS AND THEIR ORBITAL ELEMENTS

Orbital Velocity, km/sec			Periods of Revolution (Terrestrial Days) Average Value		Axial Rotation Period	Gravitational Acceleration cm/sec^2	Surface Gravity Relative to the Earth's
At Perihelion	At Aphelion	Avg.	Sidereal	Synodic			
13.69	12.44	13.05	4332.6	398.8	9 hrs. 50 min.	2620	2.67
10.18	9.14	9.64	10759.2	378.1	10 hrs. 14 min.	1150	1.17
7.12	6.48	6.80	30687	369.6	10 hrs. 47 min.	813	0.83
5.47	5.38	5.43	60184	367.5	8-15 hrs.	1130	1.15
6.10	3.67	4.81	90700	366.7	?	>2000	>2

Average Velocity, km/sec			Duration of Transfer Flight (Earth Days)		No. of Satellites	Radius of Sphere of Influence, Thousands of km	Radius of Sphere of Attraction, Thousands of km
Circular	Escape (Second Cosmic)	Minimal Velocity for Flight from the Earth	Along an Ellipse	With the Third Cosmic Velocity of 16.7 km/sec			
.55	60.4	14.2	2 yrs. 267 days	1 yr. 39 days	12	45870-50540	22890-25220
.66	36.4	15.2	6 yrs. 18 days	2 yrs. 194 days	10	51500-57580	22770-25460
.07	20.8	15.9	16 yrs. 14 days	6 yrs. 282 days	5	49350-54250	18090-19880
.57	23.7	16.2	30 yrs. 225 days	12 yrs. 343 days	2	86100-87590	32090-32650
.43	~15	16.3	45 yrs. 119 days	19 yrs. 91 days	?	26670-44170	7420-12290

FOLDOUT FRAME 2

TABLE 3

Name of the Planet's Satellite	Avg. Distance from the Planet, Thousands of km	Diameter, km	Mass, g	Avg. Density, g/cm^3	Gravitational Acceleration at the Surface *	Escape Velocity at the Surface, km/sec	Eccentricity	Inclination of the Satellite's Orbital Plane to the Planet's Orbital Plane, Degrees	Sidereal Period of Revolution, Days
Jupiter									
Ganymede	1071	5000 ± 75	$15.4 \cdot 10^{25}$	2.35	0.167	2.92	0.0015	3.06	7.15
Callisto	1884	4700 ± 75	$8.7 \cdot 10^{25}$	1.59	0.106	2.24	0.0075	3.02	16.68
Io	421.8	3470 ± 50	$6.98 \cdot 10^{25}$	3.19	0.158	2.34	0.0000	3.07	1.76
Europa	671.4	3100 ± 60	$4.68 \cdot 10^{25}$	3.03	0.134	2.03	0.0003	3.07	3.55
Saturn									
Titan	1222	4850 ± 50	$1.38 \cdot 10^{26}$	2.32	0.160	2.79	0.0289	26.07	1594
Neptune									
Triton	353.7	3770	$1.38 \cdot 10^{26}$	4.9	0.264	3.2	0.0000	139.49	5.87

*The surface gravity of the Earth is taken as one.

However, scientists assume that a large telescope located, for example, on the Moon or Mars, will permit conducting these investigations more efficiently. It is evident from what has been said that the Solar System is a very mixed "population" — from burning hot Mercury to very cold Pluto and from celestial planets of the terrestrial group to such giants as Jupiter and Saturn.

How did such a complex group of varied celestial bodies come into existence? What has their past been? What awaits them in the future? The answers to these and other questions are of exceptionally important practical significance to the inhabitants of the Earth.

Satellites of the Planets

Up to now 32 of them have been discovered. No satellites have been discovered for Mercury, Venus, and Pluto. However, if the presence of yet undiscovered satellites with a diameter greater than 1/2 km belonging to the planets near to us can hardly be expected, then Jupiter may possibly have satellites with a diameter larger than 10 km and Saturn, Uranus, and Neptune may have satellites with larger dimensions (up to 200-400 km in diameter) which are impossible to see with contemporary telescopes. Objects of an undoubtedly planetary nature with dimensions corresponding to the Moon and Mercury stand out among the satellites. Some of their characteristics are given in Table 3.

Minor Planets (Asteroids) /28

They move between the orbits of Mars and Jupiter in the form of a so-called asteroidal ring situated at a distance of about 25 astronomical units from the Sun. They move in one direction, completing a complete revolution around our daily star in 5-6 years. On January 1, 1970, 1746 asteroids had been recorded, and they have been entered into a special catalog. The largest of them — Ceres — was discovered on the first day of the nineteenth century. Its diameter is 768 km. The smallest asteroid has a diameter of 1 km. Along with the asteroids moving along almost-circular orbits, one also encounters asteroids which possess exceedingly elongated elliptical trajectories. Some of them pass within the orbit of Venus (for example, Hermes) and even move inside the orbit of Mercury. Observations of the asteroids show that they are shapeless blocks. The asteroids do not have atmospheres. It is suggested that they were formed as a result of the disintegration of one or several planets of the Solar System. The total number of asteroids which may be discovered with the help of the largest telescopes is estimated to be 50,000.

Comets

This word in translation denotes "hairy" or "long-tailed" stars. During the entire period of observational astronomy more than 2,000 appearances of comets have been noted in chronicles of various nations. Comets are special /29 objects of the Solar System both with regard to their external appearance and physical characteristics and also with regard to their motion. In contrast to the asteroids, they consist of a nucleus surrounded by an envelope consisting of small particles of matter solidified at very low temperature. This complicated conglomerate of frozen ice and the usual refractory compounds begins to evaporate as it penetrates into the inner reaches of the Solar System, and a hazy gaseous envelope is formed upon its approach to the Sun under the influence of its thermal radiation. While the comet is located far from the Sun, it has the shape of a faintly luminous obscure circular little shape, and it is difficult to observe it. But upon its closest approach to the Sun (at perihelion) luminous gases and dust particles emanate from the nucleus, which is heated by the solar rays, and the comet's brightness sharply increases due to this. The dimensions of the head of comets are very large in comparison with the dimensions of the Earth; however the solid nucleus of comets has a radius of several kilometers in all, and many have even smaller radii. The gaseous and dust particles flowing out from the nucleus do not remain in the comet's head, but they are pushed away from the nucleus by solar radiation pressure in a direction opposite to the Sun. Stretching out in a continuous flow, they form the comet's tail with a length of hundreds of millions of kilometers. Losing a significant portion of its material, the comet forms a large luminous envelope in space which, together with the nucleus, constitutes its head. The gases, absorbing solar light, give their own emission spectrum in the form of individual bright bands belonging to various molecules. It is not without interest to remark that some comets which have passed through the Solar System have forever receded from it, while others, such as the so-called periodic comets (about 40 of them have been discovered) have, on the contrary, flown past the Sun along a very elongated orbit and return again to it after a specific time. Thus, for example, Halley's comet — the most famous of the periodic comets — returns to the Sun at a rigorously specific time.

The density of the envelopes of comets is only a few ten-thousandths of the terrestrial atmosphere's density. Our planet has already repeatedly been embedded in the tail-part of comets. The last time this occurred was on May 20, 1910, when the Earth was immersed in the tail region of Halley's comet without having experienced any ill effects. The next passage of this comet will occur about 1986.

Meteoric Objects

Solid particles — the so-called meteoric objects — move in interplanetary space along uncalculated orbits around the Sun with enormous velocities (up to 40 km/sec). Flying into the terrestrial atmosphere at enormous speed, they are heated up from the friction of the air, become incandescent, and give rise to luminous phenomena such as showers, the so-called meteors. The phenomena of meteors, which have been studied in the course of the last century and especially intensively in the last two decades, and also direct experiments carried out on /30
spacecraft, indicate the presence of matter in interplanetary space which is in a finely-crushed state and which moves in the form of individual particles or clusters of them. The orbits and parameters of the motion of certain meteor streams are known, and an encounter with them can be calculated. This dusty material is distributed very non-uniformly in space. A denser dust envelope is formed around the large objects (planets and their satellites) as a result of gravitational attraction. Condensations of dust, forming various dusty "clouds" or meteor swarms — streams, can be produced in interplanetary space itself. Moving along their rigorously determined orbits, they periodically encounter the Earth, and then we observe meteor streams ("falling stars") incident on the Earth. Many of them have been assigned their own names according to the constellations in whose direction they are visible. Their falling is confined to certain times of the year. For example, the Perseids occur on August 10-14, the Leonids on November 16-17, the Geminids on December 12-13, and so forth. The number of "falling stars" (meteors) varies from several to many thousands. For example, on October 9, 1933 the intensity of meteor falls reached 130,000 per hour.

Bolides and Meteorites

The largest meteoric objects entering the Earth's atmosphere give rise to appearances of large bright meteors or fireballs exceeding the brightness of Venus. Such bright meteors are called bolides. Due to the high temperature, a bolide melts and disintegrates into individual sections. These remnants of the meteoric object broken up in the atmosphere which are incident on the Earth are called meteorites.

The investigation of them has shown that on the basis of their mineralogic composition, the majority of them are stony and only a few are iron or iron-stony. The chemical composition and structure of meteorites indicates with assurance that they are fragments of the crust of planetary objects.

Several years ago the Polish astronomer Kazimir Kordilevskii discovered the existence of dust clouds moving around the Earth near the libration points. This discovery was confirmed by other astronomers. In December of 1966 Kordilevskii communicated his new discovery, made on an expedition of Polish astronomers in Africa. They established that a significant fraction of the illumination of the zodiacal light is located in the plane of the Moon's orbit and that the Earth is thus surrounded by a ring of meteoric material similar to Saturn's ring. Observations carried out by spacecraft indicate the presence around the Earth of a rather dense collection of the finest dust, which is constantly entering and being dissipated in the Earth's atmosphere. On the basis of the latest data the Earth encounters from 2 to 20 thousand tons of meteoric particles everyday. There were attempts to estimate the amount of material brought to the Earth, but these data have a very large dispension (from 10^4 to 10^9 tons per day). /31

In the recent past outer space was imagined to be a uniform and structureless vacuum, practically devoid of any physical properties except the characteristic inherent in "empty" space of containing in itself matter, fields, and radiation. However in the course of investigations with the help of spacecraft in near-Earth outer space, radiation belts were discovered, namely, three-ring shaped regions "filled" with charged particles, and also the geocorona, the tenuous hydrogen envelope of the Earth with an extent of 30,000 km, and a belt of micrometeoric dust located at altitudes of from 300 to 500 km above the Earth's surface.

Near-Earth outer space consists of a varied and complex structure of tenuous matter, space dust (micrometeors), gravitational and magnetic fields, and electromagnetic radiations. A structure of interplanetary space is no less complicated. It is filled with magnetic fields and streams of solar plasma which comprise a tenuous atmosphere of the Sun extending out to the orbit of Mars and possibly further. Cosmic rays of galactic origin, solar cosmic rays, plasma, magnetic, gravitational, and other fields are found in very complex interaction and interrelationship.

If we thoughtfully glance at the Solar System. taking into account the masses of the planets and their satellites which populate it, from the direction of the North or South Pole of the Earth, for example, interplanetary space would seem completely empty to us. Actually if we imagine the Sun as a sphere whose diameter is 70 cm (the size of a large ball), the diameter of the planetary system out to the orbit of Pluto would amount to 3 km, and the Earth and Venus would be lost in this space like peas. The sizes of Mars and Mercury would be even smaller.

All of interplanetary space can be conditionally divided into two concentric zones: the "warm" zone and the "cold" zone. Their boundary lies between the orbits of Mars and Jupiter. This division into two sharply dissimilar temperature zones has a very significant meaning to the hydrologic, life-support, and other characteristics of planets.

The density of the interplanetary medium is estimated to be 10^{-22} g/cm^3 on the average. What does this mean? If the matter were imagined to be pure iron, then one atom of it would be contained in 56 km^3 of space, and if it were filled with hydrogen, there would be one atom per km^3 of space.

Motion of the Planets

The Solar System is an enormous disk. The axis of rotation of the Sun itself is inclined to this disk at an angle of about 83°. The plane of the Earth's equator is inclined to the ecliptic at an angle of 23°27'. The inclin- /32
ation of the equatorial plane of Mars to the plane of its orbit is approximately the same as that of the Earth; it is equal to 24°48'. The planes of the equators of Venus and Jupiter lie almost in the ecliptic plane, and their rotational axes are almost exactly perpendicular to it. All the planets move around the Sun along elliptical orbits[4], in one and the same direction, in the counter-clockwise direction if one observes from the direction of the North Pole of the celestial sphere. The orbital planes of all the planets almost coincide with each other and are situated near the plane of the Sun's equator. The angle of inclination of the orbits of the planets to the ecliptic plane is insignificant (up to 7° with the exception of Pluto: it has an inclination of 17°). These facts make possible the complete use of the orbital speeds of the planets for flight along interplanetary trajectories.

Due to the ellipticity of the orbits, the distance of each planet from the Sun varies periodically, it is true, within small limits. A planet's speed of motion along its orbit also varies: the planet has the greatest velocity upon passing that point in its orbit nearest to the Sun, which is called perihelion, and it has the smallest velocity upon passing that point in its orbit most distant from the Sun, which is called the aphelion. For example, our planet has a speed of 29.27 km/sec at the most distant point of its orbit (aphelion — A) and a speed of 30.27 km/sec at the nearest point of its orbit (at perihelion — P).

The nearer a planet is to the Sun, the faster is its velocity. The periods of revolution of the planets around the Sun are associated with their average distance from the Sun by the relationship: the squares of the revolution times of the planets are proportional to the cubes of their average distances from the Sun (Kepler's third law). This law "ties together" all the planets into a single system and permits calculating the average distances of the planets from the Sun in astronomical units of length (A.U.s.) from observations of their revolution periods. The Twelfth International Astronomical Union (1964) adopted as such a unit the average distance from the Earth to the Sun, which is equal to 149,597,900 km.

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[4]Since the attraction of the Sun and other planets exerts an effect on the orbital motion of the planets, their orbits are not exactly elliptical.

The majority of the planets rotate about their axes in the direct sense, i.e., from west to east, in the direction of the orbit, with the exception of Venus, which very slowly rotates in the reverse direction, and Uranus, which is lying on its side. Almost all the satellites of the planets also move in the same direction as the axial rotation of their planets. Only part of the satellites move in the direction opposite to the planet's rotation. These are the satellites of Neptune — Triton and Nereid, the two inner satellites of Uranus, the satellite of Saturn named Phoebe, the four outer satellites of Jupiter, and a fifth satellite of Uranus. Some groups of satellites form a miniature replica of the planetary system (Uranus' system, the main satellites of Jupiter). Peculiarities in the structure of the Solar System and the motion of the planets and their satellites indicate that the Solar System is not a random collection of celestial bodies having a different origin, but represents a integral /33
regularly evolving system.

The motion of each planet can be easily imagined if one knows the shape and position of its orbit in space and also the position of the planet in its orbit. There are six quantities which characterize these data. Two of them determine the orbit's position relative to the ecliptic plane, three determine the dimensions and orientation of the orbit in its plane, and one determines the planet's position in its orbit at a specific instant of time. Since four of these parameters have a direct relationship to the problems of interplanetary transfer flights discussed in this book, it seems advisable to dwell on their characteristics in some detail (Figure 2).

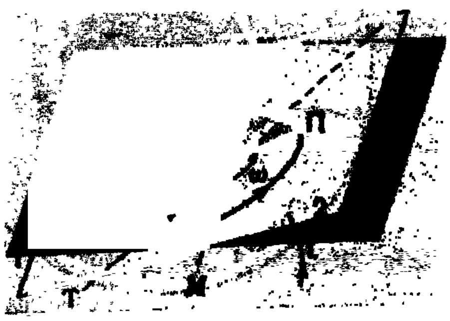

Figure 2. Elements of Planetary Orbits: NM, Line of nodes; i, Inclination angle of the orbit's plane to the ecliptic plane; Ω, Longitude of the ascending node; A, Aphelion and P, Perihelion of the planet's orbit; ω, Angular distance of the perihelion from the node; T, Equinox. 1, Ecliptic plane; 2, Plane of the planet's orbit.

The orbit of any celestial body — member of the Solar System — lies in a plane. The principal plane in space relative to which the position of any other plane is determined is the ecliptic plane, i.e., the plane of the apparent annual motion of the Sun.

The plane of an orbit is inclined (as shown in Figure 2) to the ecliptic plane by an angle i, which is called the inclination of the planet's orbit to the ecliptic. The Earth's orbit, as that of any other planet, has two special points — the apsides. At one of them — at aphelion (point A), the Earth is situated at its maximum distance from the Sun, and at the other — at perihelion (point P), it is situated at its minimum distance from the Sun. The line which joins the points of the apsides is the major axis of the ellipse of the terrestrial orbit. One-half of the major axis is the so-called semimajor axis. The line of intersection of the orbit's plane and the ecliptic plane bears the designation of line of nodes. The point of a planet's orbit coinciding with the ecliptic plane at which the

Earth is located upon passing from the southern hemisphere of the celestial sphere to the northern is called the longitude of the ascending node Ω — the angle between the direction to the vernal equinox point and the line of nodes.

The compression of the ellipse is characterized by the eccentricity

$e = \frac{\sqrt{a^2 - b^2}}{a}$, where b is the semiminor axis of the planet's orbit. The eccentricity is also equal to the ratio of the distance from the ellipse's center to its focus on the major axis.

The eccentricities of the orbits of the major planets are not large; the /34
largest eccentricity is that of Pluto, which is 0.247, and the smallest eccentricity is that of Venus, which is 0.007. Mercury has an eccentricity of 0.205, while that of the Earth is 0.017. If we draw the Earth's orbit with a semimajor axis of one meter, the semiminor axis will be 1/7 mm shorter in all.

The orbits of spacecraft, such as satellites of the planets and interplanetary spacecraft, near the planets are characterized by analogous elements with the only difference being that the inclination of their orbits is specified with respect to the plane of the planet's equator, and the designations of the extreme points of the orbit include the planet's name. For artificial satellites of the Earth these points are called perigee and apogee (from the Greek "Gaia" — the Earth), for Venus — peri- and apovenus, for Mars — peri- and apomars, for Saturn — peri- and aposaturn, and for Jupiter — peri- and apojove (from the Latin name for Jupiter — Jove); the extreme points of the orbits of artificial Moon satellites are called peri- and aposelene.

Conditions for Observation of the Planets

Based on the conditions of observation from the Earth, the planets are divided into the inner (or inferior) and outer (or superior) planets. The inner planets include Mercury and Venus, whose orbits are situated completely inside the terrestrial orbit. All the remaining planets belong to the outer group. Since the conditions for observation of the outer planets differ very significantly from the conditions for observation of the inner planets, we will discuss them separately.

Let us begin the discussion of conditions of observation of the outer planets with the configuration called conjunction (the position AA' in Figure 3). In this case the planet is located on a straight line behind the Sun. It is inaccessible to observation. After some time the planet and the Earth will occupy the position BB'. The planet will be visible west of the Sun, and its western separation will increase daily, and because of this it will rise earlier and earlier each day, and the conditions for its visibility will be noticeably improved. In the position CC' the planet rises about midnight and is visible right up to dawn. At position DD', which is called opposition, it rises in the /35
evening at sunset and sets in the morning at sunrise, i.e., it is visible all night.

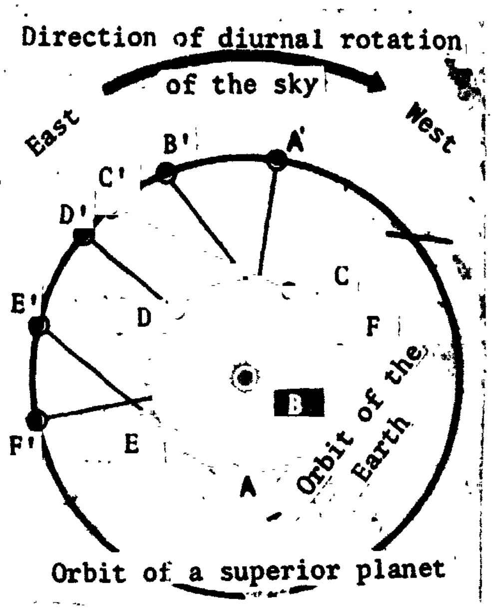

Figure 3. Configurations of Superior Planets.

If at this time the planet is located at its minimum distance from the Sun, the conditions for its observation are the most favorable.

After opposition the separation of the planet to the east of the Sun begins, and the conditions for its visibility gradually deteriorate: with each day it sets earlier. In the position EE' the planet lies at an angle of 90° east of the Sun. At the time it sets, it is located in the southern part of the sky and sets about midnight. After some time the planet now becomes visible against the background of the evening twilight, and then its next conjunction with the Sun approaches (position FF').

Observations of Mars from observatories situated in the temperate zone of the northern hemisphere are very difficult since at this period it is located low above the horizon and moves among the southern constellations of the sky — Sagittarius, Capricorn, and Aquarius. Crossing low above the horizon, it appears in the sky for only a short time. It is necessary to observe it through a large thickness of turbulent agitated air. Due to this planet's image on photographs appears indistinct, and therefore it is impossible to investigate "fine" surface details on them. The observational conditions are more favorable from observatories located in the equatorial region and in the southern hemisphere of our planet, because Mars is located almost at the zenith above certain regions of the Earth.

Let us begin the conditions for observation of the inner planets with the configuration (Figure 4, position AA') in which an inner planet, for example, Venus, is situated at so-called inferior conjunction[5]. Since its orbit is inclined to the plane of the Earth's orbit by 3°, it is located at this time somewhat above or below the Sun, and therefore in the daytime Venus is hidden in the luminous aureole of our daily star and it is difficult to observe it at this time: the bright background of the sky from the light scattered by the Earth's atmosphere is a hindrance. It is possible to see it only in a telescope. After some time Venus, having a larger orbital velocity than the Earth, will begin to move away to the west of the Sun, and it will become accessible to /36

[5]Conjunction with the Sun is the position of a planet in which its longitude (in the ecliptic system of coordinates) is equal to the longitude of the center of the Solar disk. Conjunction can be superior or inferior. At superior conjunction the distance from the observer to the planet is larger than the distance to the Sun (the planet is located behind the Sun), and at inferior conjunction it is smaller (the planet is situated between the Sun and the observer).

observation in the mornings before sunrise. In the course of the subsequent mutual shifting of the planets along their orbits this western elongation from the Sun gradually increases and finally attains the largest angular value, the so-called maximum western elongation[6] (the position BB'). Subsequently the distance from Venus to the Sun gradually diminishes, and the conditions for its visibility in the morning deteriorate and finally at position CC', at so-called superior conjunction, it again falls within the bright aureole of the Sun and will be "hidden" in it in the daytime. Nevertheless Venus continually moves away more to the east (to the left) of the Sun and becomes visible now in the evenings after sunset. At the position DD' (eastern elongation) the best conditions for its observation are again produced. At this position its brightness is very great; it exceeds even the brightness of the brightest star — Sirius — by almost a factor of 13! Even the Roman scientist Plinius, who lived in the first century of our era, reminiscing about Venus said: its light is such that it is the only one of the planets which casts a shadow. Nevertheless the conditions for its observation deteriorate with each day, until the planet again arrives at inferior conjunction (the position EE'). Venus is never observed in the sky during an entire night. Either it, like an evening star, sets a few hours after the Sun, or, like a morning star, it appears shortly before sunrise. Assuming that this is two different planets, the ancient Greeks gave them different names — Phosphorous and Hesperus, corresponding to the morning and evening visibility of the planet.

During the entire cycle discussed by us the distance to Venus has varied from 40 million km at its nearest approach to the Earth (inferior conjunction) to 260 million km (superior conjunction). Unfortunately, when it is nearest to the Earth Venus has its unilluminated side turned towards us, and therefore it is not visible. Near this position Venus shows us a very narrow crescent. The further it recedes from the Earth, the wider the crescent becomes, but in return the smaller it becomes. Venus is the only one of the planets which one can observe even in the daytime with the unaided (by binoculars or a telescope) eye when the Earth's atmosphere is very transparent. It is visible in the bright golden rays of the rising or setting sun. As if it were a small diamond, it sparkles in the blue vault of heaven, adorning it and never failing to attract the attention of people. /37

Why does Venus shine so brightly? The fact is that it is far closer to the Sun than the Earth and Mars; therefore the intensity of the Solar illumination of its atmosphere is approximately two times greater than the intensity of the illumination of the Earth's atmosphere. And it is well-known that the illumination of objects is enhanced in proportion to their nearness to the source of light in inverse proportion to the square of the distance. But since Venus is 1.38 times closer to the Sun than the Earth, the illumination of its surface

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[6]Elongation is the angular distance of a planet from the center of the Solar disk (relative to the observer). The largest elongation or largest separation is the position of an inferior planet at which its angular distance to the Sun is a maximum. The largest elongation is called western if the longitude of the Sun is larger than the longitude of the planet and eastern if it is smaller.

is $(1.38)^2 = 1.9$ times greater. The dense reflecting white cloudy covering of Venus has a very great reflectivity. It reflects about 60% of the Solar radiation incident on it; all the radiation of the visible Solar spectrum is reflected almost the same. This is characteristic of planets having an atmosphere. Celestial bodies which do not have atmospheres possess very low reflectivities. Thus, for example, Mercury and the Moon reflect only about 7% of the Solar radiation in all.

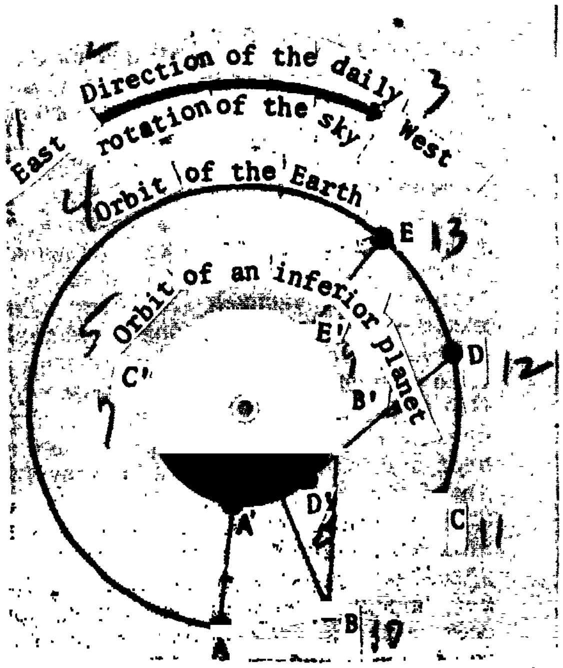

Figure 4. Configurations of Inferior Planets.

Above, we said that the best conditions for observation of the inner planets appear at their greatest angular separation from the Sun and at a sufficient difference of the declinations of the planet and the Sun. But not all the best elongations are equally suitable for observations. In the evenings Venus is quite easily visible in the winter or spring, and in the mornings, in the fall or winter. At these times of the year the diurnal path of Venus on the celestial sphere lies above the Solar path, and the planet is quite easily visible. The duration of its observation lasts for four hours. The most unfavorable time of the year to observe Venus at elongation is in the summer. At this time the diurnal path of the Sun itself crosses so high in the sky that Venus cannot appear noticeably higher than the Sun. Only in August are the conditions of its visibility improved.

From eastern elongation to inferior conjunction takes usually 72 days, and the same amount of time from the conjunction to western elongation. After 220 days superior conjunction begins, and after another 220 days, we have a new eastern elongation, after which the cycle is repeated. Venus reaches maximum brightness a month after eastern elongation and a month before western elongation. At this time it is visible with the unaided eye even in the daytime, but in order to spot it, it is necessary to know its position in the sky.

We will briefly recite the conditions for the observation of Mercury.

The legend according to which Nikolas Copernicus regretted on his deathbed only that he had never seen Mercury is probably close to the truth. Actually, Mercury is a difficult object for observations. It is small in size and very close to the Sun. As a result the brightness of the sky and the scattered Solar light greatly interfere with the observations. Mercury is never more distant from the Sun than 28°. This is almost two times less than the angular distance to Venus from the Sun. During the day the planet is located above the horizon, and it is briefly visible only during rare periods at a low altitude. In the evening as twilight fades away (for eastern elongations) or before morning (for western elongations), Mercury can be noticed in the sky. /38

Mercury's declination is most often close to the Sun's declination, and therefore it "drowns" in its dazzling light, which very severely hinders observation. Just as for Venus, the time of year at which its elongation occurs is of great significance for observation of Mercury. It moves near the ecliptic; therefore during the fall months when the ecliptic does not rise high above the horizon in the evenings, Mercury will be "drowned" in the Sun's rays even at large eastern elongations. In the springtime it is impossible for the same reasons to observe Mercury before dawn at western elongations. It is possible to observe Mercury best of all in the fall months at western elongations (morning visibility) and during the spring months at eastern elongations (evening visibility). Since Mercury is above the horizon more or less close to the place of sunset or sunrise, it is almost impossible to see it in the brightening sky, but especially in the brightening morning or in the still waning evening twilight. The conditions for the observation of Mercury are better in the southern regions of the Soviet Union's territory, where the twilights are shorter and the ecliptic is inclined higher above the horizon than in the middle geographic latitudes. Mercury is usually inaccessible to observations at high geographic latitudes.

At the epoch[7] of inferior conjunctions, it is possible to observe an exceedingly rare but very interesting, from the scientific point of view, phenomenon if the inner planet is near to one node or other of its orbit, namely, the transit of Mercury across the Sun's disk. This phenomenon takes place once every several years in May or November. Every 217 years there occur 9 May and 20 November transits — the May ones occur every 13 and 33 years, and the November ones every 7 or 13 years. After each May transit a November transit of Mercury across the Sun's disk occurs 3.5 years later. In the near future such a phenomenon will be observed on November 10, 1973, November 13, 1986, November 6, 1993, and November 15, 1999.

For a long time it was assumed that Mercury's rotation about its axis was synchronous with its orbital motion (88 days); therefore Mercury has one side turned towards the Sun. Radar observations (1965) have established that the period of its axial rotation is 59 ± 3 days, i.e., it is close to 2/3 of the revolution period (2/3 × 88 = 58.65 days). Therefore the synodic period for Mercury is equal to 116 terrestrial days. "Solar days" on Mercury, namely, the time interval between two successive sunrises observed from one or the other point on Mercury, are equal to 176 terrestrial days, or two Mercurian years. This is very close to 1.5 synodic periods. Consequently, after each three synodic periods the same part of the planet's disk at the very same phase can be observed from the Earth. But based on the remarkable coincidence associated with the fact that three synodic periods of Mercury are close to one terrestrial year, the most /39

[7]The epoch is the instant of time for which the value is given for some quantities or other which vary with time and which determine the orientation of the coordinate system (or determine the position of a celestial body).

favorable conditions of Mercury's visibility are also encountered every three synodic periods. At each such favorable arrangement of the planets the very same details will be visible on Mercury's disk at the very same phases. But since three synodic periods are not quite equal to one terrestrial year, this "stroboscopic" effect gradually gets out of phase.

However, a comparison of observations carried out over 5-6 terrestrial years will give almost the very same result. It is precisely due to this "stroboscopic resonance" that astronomers who observed Mercury visually were led into the error of having verified that the period of the planet's rotation was equal to 88 days.

A transit of Venus across the Sun's disk occurs significantly more rarely. The last transit of Venus across the Sun's disk was on December 6, 1882, and the next ones will occur on June 8, 2004 and June 6, 2012.

Two periods are distinguished in the revolution of planets — the synodic and the sidereal (stellar). Since these periods have great significance in the calculation of the trajectories of interplanetary spacecraft, it is necessary to discuss them in somewhat greater detail.

Synodic and Sidereal Revolution Periods of the Planets

The synodic period of revolution of a planet is the time interval between two successive similar positions of a planet relative to the Sun for a terrestrial observer (for example, between oppositions).

The sidereal or stellar period is the period in which a planet makes a complete revolution around the Sun and returns to the same stars.

From the physical point of view it is more important to know the sidereal period of a planet, i.e., the revolution period with respect to the Sun, than the synodic period, which depends on a randomly selected position of the Earth relative to the planet. However, it is possible to measure only the synodic period directly from the Earth. Therefore it is possible to use it to determine the planet's sidereal period after its synodic period has been measured. The duration of the sidereal period P is connected with the synodic period S by the synodic motion equation $\frac{1}{S} = \frac{1}{P} - \frac{1}{E}$ for an inferior planet, and $\frac{1}{S} = \frac{1}{E} - \frac{1}{P}$ for a superior planet, where E is the sidereal revolution period of the Earth around the Sun or the sidereal year, i.e., the time of a complete revolution of the Earth around the Sun if the observer is located on the Earth.

For example, the synodic period of Mars is equal to 780 days. Its sidereal period can be determined from the equation /40

[illegible] or [illegible] sid [illegible] days

The mean synodic period of Mercury is equal to 116 days. And its sidereal period can be found by substituting this value into the synodic motion equation:

$$\frac{1}{P} = \frac{1}{365.25} + \frac{1}{116} \text{ or}$$

$$P = \frac{[illegible]}{116 + 365.25} = [illegible] \text{ days.}$$

The synodic revolution period of Venus is equal to 584 days. This means that for an encounter of a spacecraft with Venus favorable launch conditions for it should repeat precisely after this period, which is equal to 1.599 terrestrial years. Thus if an inferior conjunction occurs in January when the Earth is at perihelion, the next January inferior conjunction will occur only after 5 synodic periods of Venus or in 8 years. And this indicates that similar configurations of Venus repeat in 8 years and on the same dates. Due to this fact the possibility suggests itself of making up "scheduled" transfer flights to Venus with an 8-year cycle.

The values of the synodic revolution periods of the planets, which are cited in Tables 1 and 2, are the average periods. The duration of some specific period or other depends on the eccentricities of the Earth's and the planet's orbits and the mutual arrangement of their semimajor axes. Thus, for example, the actual periods for Mars oscillate relative to a value in the range from 765 to 811 days.

Let us now discuss two important distinctive features among the characteristics of the planets which have a direct relationship to interplanetary transfer flights.

The "Sphere of Attraction" and "Sphere of Influence" of a Celestial Object

The sphere of attraction of a celestial object is the region of space within which the gravitational attractive forces of a specific celestial body dominates (Figure 5). In order to clarify the essence of the problem, let us turn to a specific example. Let us imagine that a spacecraft is moving in the Moon's direction along a straight line joining the centers of the Earth and the Moon. Traveling along it, the spacecraft first overcomes the gravitational field of the Earth; then it reaches the neutral point at which the Earth and the /41 Moon attract the spacecraft with identical force but in opposite directions. Passing this boundary, the spacecraft moves into the sphere of the Moon's dominating attraction. It has been determined that this sphere has a radius of 43,000 km, and the radius of the Earth's sphere of attraction is equal to 260,000 km. The term "sphere of influence of a celestial body" has a different meaning. It is well-known that the gravitational field of any celestial object extends practically to infinity. Many celestial objects of the Solar System simultaneously act on a spacecraft flying, for example, to Mars, and their gravitational fields, superimposing one on another, form a complex mosaic of physical space.

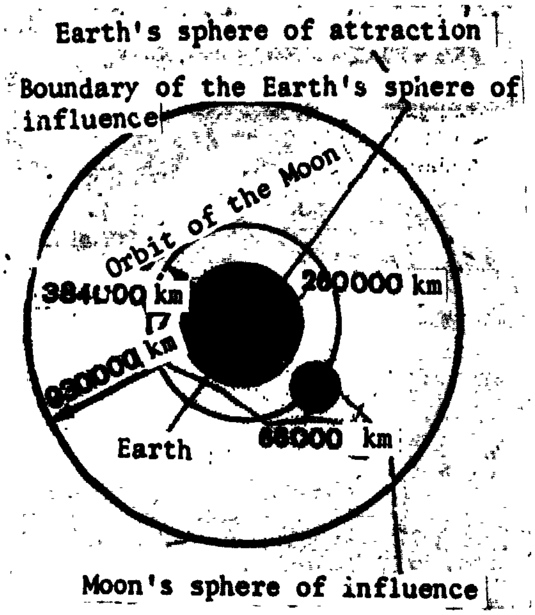

Figure 5. The Earth's Sphere of Attraction and the Sphere of Influence of the Earth and the Moon.

Such a region around a planet, in which the ratio of the force with which the planet perturbs the motion of a small object (for example, a spacecraft) relative to the Sun to the force of solar attraction is larger than the ratio of the force with which the Sun perturbs the planetocentric motion of this object to the attractive force of the planet, is called the planet's sphere of influence with respect to the Sun. This condition can be expressed by the following inequality:

$$\frac{R_{pl}}{F_S} > \frac{R_S}{F_{pl}},$$

where R_S and R_{pl} are the perturbing forces of the Sun and the planet, respectively, and F_S and F_{pl} are the attractive forces of the Sun and the planet.

The radius of a planet's sphere of influence relative to the Sun is determined by the equation

$$r = a\sqrt[5]{\left(\frac{m_{pl}}{M_S}\right)^2},$$

where m_{pl} is the planet's mass, M_S is the Sun's mass, and a is the distance between the planet and the Sun.

The principal attractive center in the Solar System is the Sun. In its turn each planet has its own sphere of influence, in which the attraction of this planet predominates.

Thus, for example, the radius of the Moon's sphere of influence relative to the Earth is 66,000 km, and the radius of the Earth's sphere of influence relative to the Sun is 930,000 km on the average. A spacecraft (SC) which goes beyond the limits of the Earth's sphere of influence with a speed different from zero is converted into an independent satellite of the Sun, namely, into an artificial planet. Therefore when the motion of a SC occurs within this sphere, one should adopt the planet as the central object and the Sun as the perturbing object. If the motion occurs outside this sphere, then it is necessary to consider the Sun as the central object and the planet as the perturbing object. /42

It is assumed in the approximate analysis of interplanetary trajectories that the SC moves in the sphere of influence of the attracting center only under the influence of the gravitational forces of the particular object. Therefore it is possible to imagine the trajectory of a spacecraft's flight from one planet to another as the successive transition from one sphere of influence to another. But since the spheres of influence of the planets are small with respect to the Sun's sphere of influence, one can assume that only the Sun's gravitational force acts on the SC over a large part of the transfer trajectory.

We have discussed in this chapter only a particle negligible by volume in the Universe, which occupies, by contemporary ideas, a space of more than nine billion light-years. The most distant planet of the Solar System — Pluto — is 40 astronomical units from the Sun. But this distance is negligibly small in comparison with the distance even to the nearest star of our Galaxy — Proxima (it is Alpha Centauri), which is 271,000 astronomical units away, i.e., 6,800 times further than Pluto. If the light from the Sun arrives at the Earth in 8 and a fraction minutes, then it reaches us from the nearest star in 4 years 3 months and 20 days.

No large material objects have been detected in this enormous space between the Solar System and the nearest stars. Therefore one can say that the Solar System is isolated in space and no external forces are acting on it.

CHAPTER 3.
MARS: CONTEMPORARY IDEAS

The orange planet captures our imagination the more strongly, the more we find out about it. Based on the abundance of hypotheses capturing the imagination, it ranks in first place. /43

Since the Italian astronomers A. Secchi and G. Schiaparelli notified the World about the presence on Mars of a system of rather narrow and straight lines which Schiaparelli called canals, and P. Lowell advanced his hypothesis about the possibility of intelligent life on Mars, this puzzling world completely has attracted the close attention of mankind. But today it has become completely evident that the best method for solving the Martian secrets are investigations of it by spacecraft providing direct contact with it.

Carrying out their own program of investigations of space objects and the planets of the Solar System, Soviet scientists proceed on the basis that, at the contemporary stage of development of science and technology, it is advisable to conduct the most important experiments with the help of automatic devices. In principle an automaton can carry out the same operations as a man can (in some cases even more), and its utilization costs significantly less, not considering the fact that the possibility of some danger for humans is excluded. "Robots" can accomplish in space operations which are physically not within the power of humans to carry out or such operations whose accomplishment by man would require the application of complicated and expensive methods with respect to providing for his safety.

The first device in the history of terrestrial civilization — the automatic interplanetary spacecraft (AIS) "Mars-1" was directed to Mars on November 1, 1962 (Figure 6). Its flight lasted 7 1/2 months.

With the help of scientific instrumentation whose data were transmitted over a radiotelemetry channel (61 radiocommunication sessions were conducted with the station), a large volume of scientific information was obtained from it. In particular it was established that the intensity of cosmic rays in interplanetary space increased to several tens of percent in comparison with measurements carried out in 1959 by Soviet spacecraft. This was probably caused by lesser solar activity. Investigations of the plasma in outer space confirmed that the ionized gaseous envelope of the Earth stretches out to altitudes of the order of 20,000 km. Again the existence of an outermost belt of charged particles discovered earlier by Soviet scientists was confirmed. At this time extensive data was obtained about the streams of interplanetary plasma and the distribution of meteoric material in the region of space more distant from the Sun than the Earth (Figure 7). /44

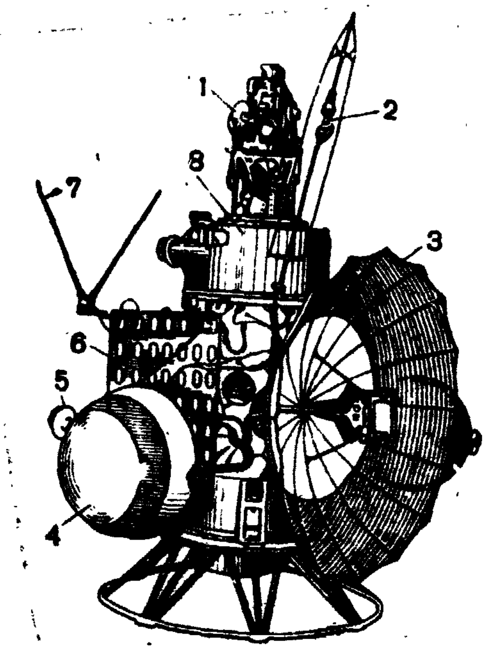

Figure 6. Automatic Interplanetary Spacecraft "Mars-1": 1, Correction motor assembly; 2, Magnetometer broom; 3, Highly directional antenna; 4, Radiator of the temperature regulation system; 5, Quasi directional antenna; 6, Solar battery panel; 7, Isotropic antenna; 8, Orbital compartment.

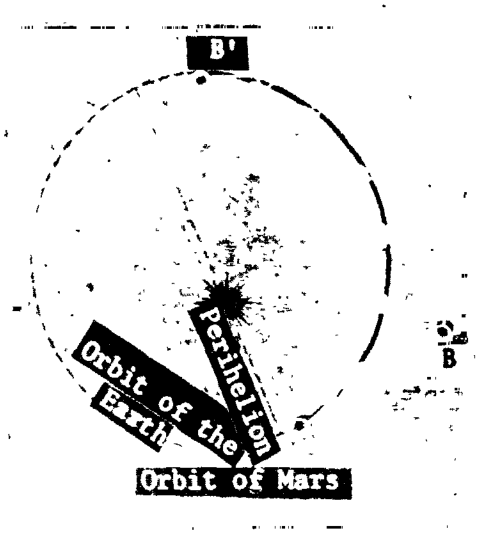

Figure 7. Schematic Diagram of the Orbits of the Earth, Mars, and the "Mars-1" Station: A, Position of the Earth at the instant of the launch of the automatic interplanetary spacecraft; A', Position of the Earth at the instant of the spacecraft's approach to Mars; B, Position of Mars at the instant of the automatic interplanetary spacecraft's launch; B', Position of Mars at the instant of the spacecraft's approach.

At a distance of 6,000-40,000 km from the Earth the spacecraft crossed the Taurid meteor stream. The number of recorded impacts of meteoric particles in the stream was approximately equal to one impact every two minutes. At a distance of 20-40 million km from the Earth the spacecraft again crossed a meteor stream which has not been identified with any other meteor stream known on the basis of terrestrial observations. The density of meteoric particles in it was approximately the same as in the Taurid stream. The approach of the spacecraft to the planet Mars occurred on July 19, 1963. It passed the planet's surface at a distance of 195,000 km, after which it went into a heliocentric orbit. Thus for the first time an interplanetary trajectory had been traversed. This experiment permitted solving a series of important engineering problems. First it succeeded in carrying out two-way radiocommunication with an interplanetary spacecraft located at a distance of 106 million km. This was a record for distant space radiocommunication at the time. It confirmed the validity and effectiveness of the basic engineering solutions embodied in the radio link: the modulation and coding methods; signal detection and extraction; and the measurement of the spacecraft's motion parameters. /45

The data obtained concerning the operation of the instrumentation and the automatic interplanetary navigation and radiocommunication systems had considerable significance for subsequent investigations of near-solar space and the study of the planets of the Solar System.

On November 5, 1964 the first launch was accomplished in the direction of the planet Mars by the American spacecraft "Mariner-3". However, it turned out to be unsuccessful. Upon a second launch occurring on November 28, 1964, the American scientists nevertheless succeeded in injecting their first automatic spacecraft "Mariner-4" into an interplanetary trajectory to Mars. This trip was marked by success. After 7 1/2 months of flight along the trajectory the spacecraft reached Mars on July 15, 1965 and photographed part of the Martian surface from a distance of 12,000-9,100 km. During the 26 minutes of the spacecraft's flight near Mars its special photographic camera made and recorded on magnetic tape 22 photographs. The photoelectronic eye captured a band with a width of 200 km and a length of 6,400 km. The photography was carried out alternately through orange and green filters. In all they succeeded in photographing about 1% of the planet's surface with a total area of 1,500,000 km^2. The length of the scanning band was equal to approximately 6,500 km and passed through the equator from the northern hemisphere to the southern. At the time of the photography, the illumination varied from full sub-solar illumination to half darkness.

Having completed the photography of the surface, "Mariner-4" disappeared behind the disk of Mars and was located behind it for about an hour. During the time of its setting and rising, i.e., twice, the radio signals transmitted by the spacecraft underwent a strong variation in phase, frequency, and power caused by the effect of the atmosphere and ionosphere of Mars. On the basis of their absorption and reflection, the scientists succeeded in determining the value of the atmospheric pressure. Values from 5 to 9 millibars[8] were obtained. The photographs were transmitted to Earth twice. About 100 craters resembling Lunar /46 craters, from 5 to 180 km in diameter, were discovered on them. Some of them have central peaks. Many craters bear the traces of erosion associated with the transport of dust by the atmosphere, and with tectonic and other phenomena. Besides the craters linear formations — small mountain ridges — were visible on the photograph. Their highest altitude does not exceed 4 km; a significant part of the crater walls are low and mildly sloping.

On November 30, 1964 a Soviet spacecraft "Zond-2" was launched in the direction of the planet Mars. An array of scientific instrumentation was contained onboard the spacecraft, including a long-distance communication system and an automatic orientation system. In particular, plasma reactive motors, which successfully carried out experiments under the complex conditions of spaceflight, were used in it for the first time in the World.

About five years passed, and on February 24, 1969 the automatic spacecraft "Mariner-6" was launched in the direction of Mars (Figure 8). Having flown 390 million km, it passed at a distance of 3,430 km from the surface of Mars on

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[8]One atmosphere is equal to 760 millimeters of Mercury or 1,013.25 millibars. One millimeter of Mercury is equal to 1.33 millibars. We note that such a pressure occurs in the Earth's atmosphere at an altitude of 30-35 km.

July 31, 1969, having a speed of 7,882 m/sec. The distance of Mars from the Earth at this time was 95.7 million km. The device approached Mars in the vicinity of its equator, and receded from it at the South Pole. Flying immediately after it, Mariner-7, launched on March 27, 1969, having flown 316 million km, flew by at a distance of 3,428 km from its surface on August 5, 1969, at a speed of 7,180 m/sec. The distance from Mars to the Earth at this time was 99.4 million km. Mariner-7 approached nearer to the Southern Pole in the daytime, and it receded on the nighttime side. The flight trajectories were selected in such a way that upon flying by Mars Mariner-6 would pass behind the planet's disk near the Northern Polar region and would photograph the surface in a large region of latitudes including the equatorial region, and Mariner-7 would pass behind the disk over the Southern Pole (Figure 9). The goal of the experiment was to photograph the planet from various distances, determine the chemical composition and parameters of the Martian atmosphere, investigate the characteristics of its ionosphere, and determine the surface temperature. /47

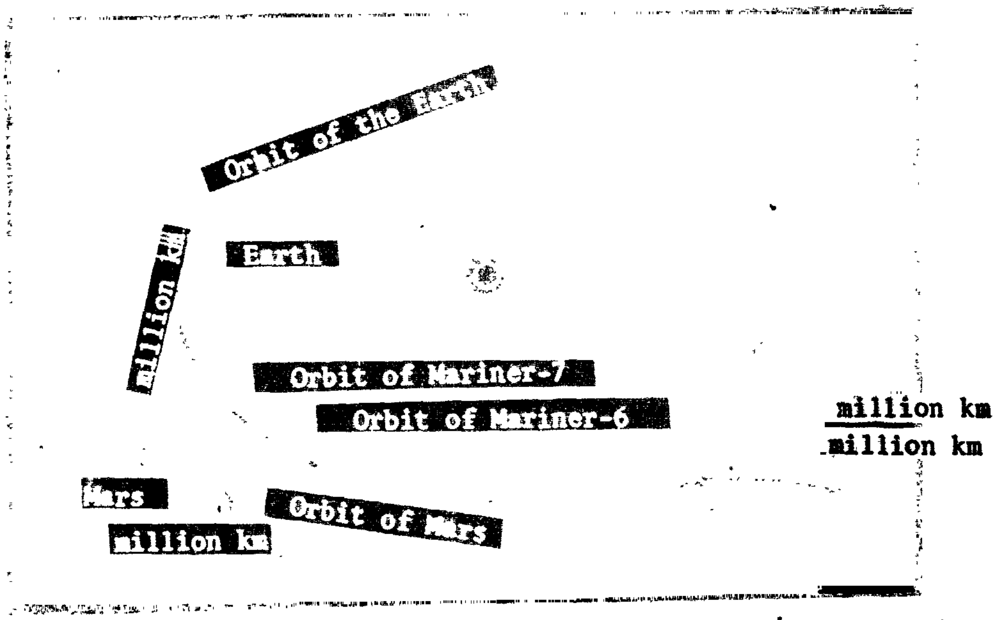

Figure 8. Flight Trajectories of the Mariner-6 and Mariner-7 Spacecraft.

Both spacecraft conducted repeatedly photographed the surface of Mars and transmitted 202 photographs to Earth (Figure 10). Mariner-6 photographed the planet's surface between the equator and the parallel 20° S, and Mariner-7 photographed a region of the planet starting somewhat north of the equator and extending to the southeast. /49

Scientists rightly have called 1971 the year of Mars. In all 57 million km separated it from our planet in the month of August. Since only once every 15-17 years does Mars pass so near the Earth, astronomers and radioastronomers all over the world concentrated their close attention on the investigation of Mars. Hundreds of telescopes and radiotelescopes continuously "watched" the orange planet. In this year Soviet and American scientists directed their own automatic explorers to Mars.

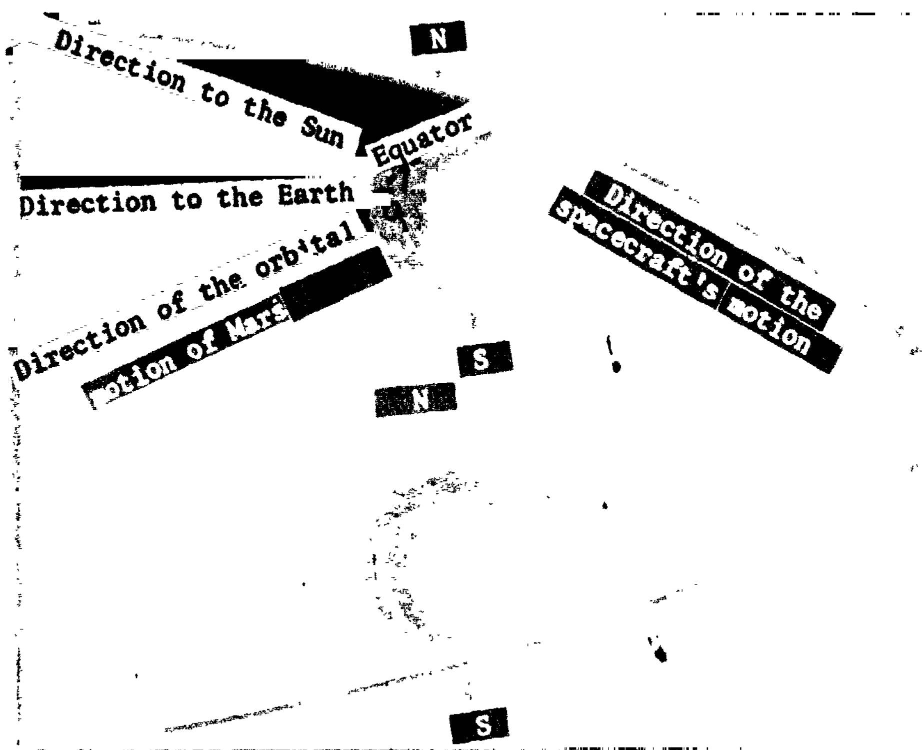

Figure 9. Flight Trajectories of the Mariner-6 (Above) and Mariner-7 Spacecraft Near Mars: 1, Switching on of the television cameras and scientific instruments; 2, Switching on of the television cameras; 3, Switching on of the digital recording equipment; 4, Start of the radio occultation period; 5, Completion of the radio occultation period.

The automatic interplanetary spacecraft Mars-2 and Mars-3 were launched on /50
May 19 and 28. Having surmounted the 192 days of interplanetary journey 470 million km in length, the Mars-2 spacecraft emerged onto a trajectory passing at a distance of 1,380 km from the surface of Mars (Figure 11). Upon its approach to the planet, a capsule was separated from it, having delivered to the surface of Mars a pennant with an image of the national emblem of the Soviet Union, and the spacecraft itself went into a near-Martian orbit whose parameters were as follows: minimum distance from the surface of Mars, 1,380 km, maximum distance, 25,000 km, and revolution period, 18 hours.

The flight of the Mars-3 automatic interplanetary spacecraft lasted for 188 days. On December 2, 1971 the descent capsule entered the planet's atmosphere after separation from the spacecraft and completed its descent by parachute, carrying out a soft landing in the southern hemisphere of Mars between the regions Electris and Thaetonis in an area having coordinates 45° S and 158° W (Figure 12). The descent station communicated television signals concerning
its landing on the surface. These signals were received and recorded onboard /51
the Mars-3 artificial satellite, and then they were transmitted to Earth during the radiocommunications sessions. No details noticeably distinguishable by contrast were detected in the small part of the transmitted panorama.

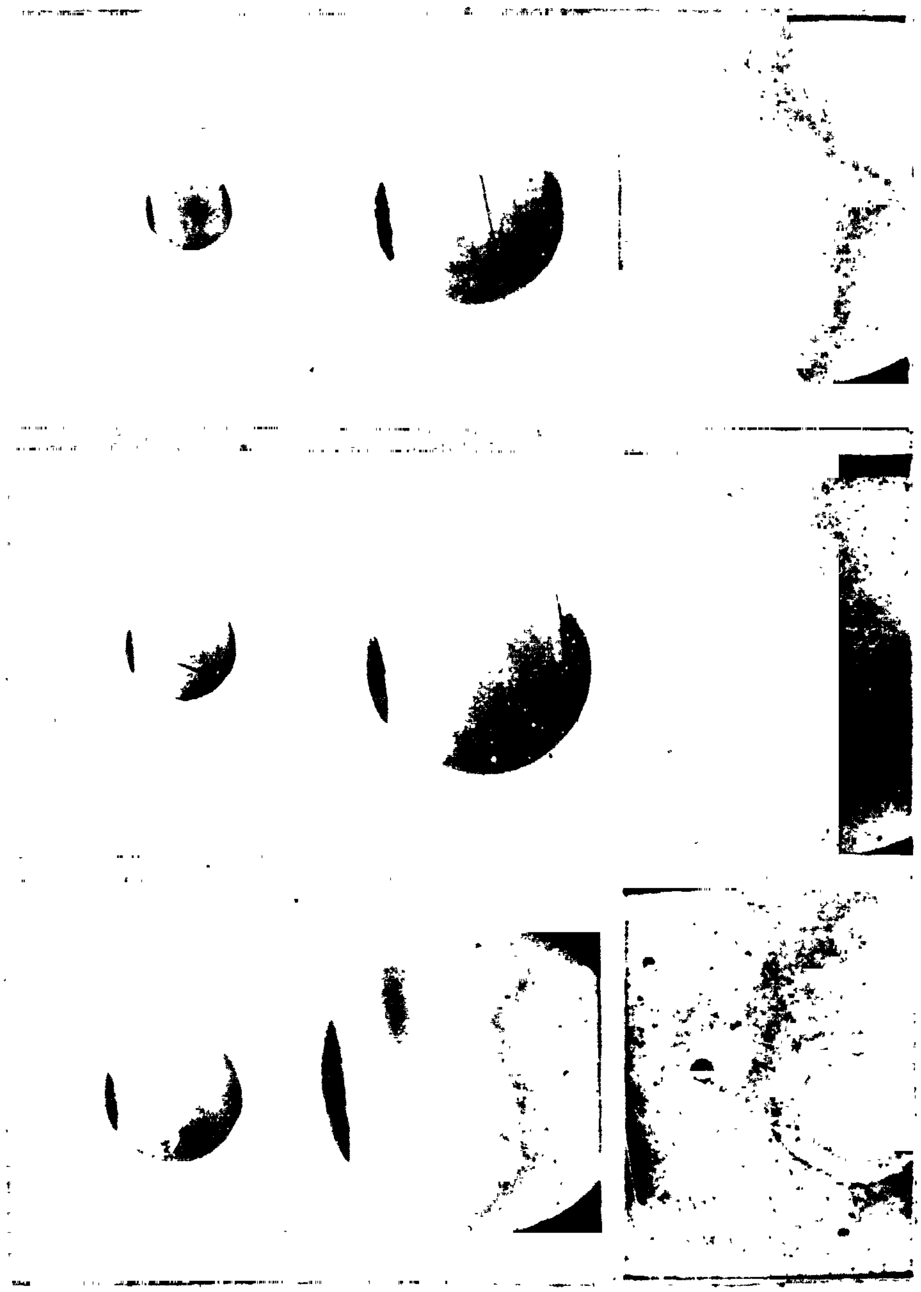

Figure 10. The Approach of the Mariner-6 Spacecraft to Mars is Shown on the Photographs. The sequence of photographs obtained from the Mariner-6 spacecraft shows the approach of the spacecraft to Mars during the period July 29-31, 1969. The fir·t photograph was taken at a distance of 1,241,350 km, and the last photograph was taken at a distance of 3,700 km. A crater having a diameter of about 38 km is visible on the last frame. If each photograph were turned by 120° clockwise, then north would be located straight up. The bright region on the photographs is the Southern Polar cap.

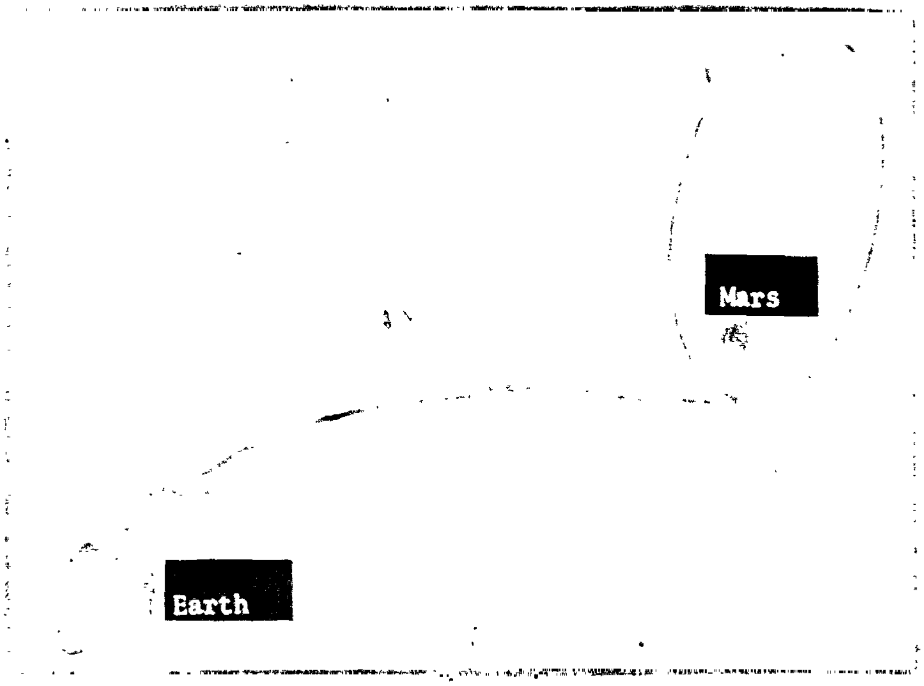

Figure 11. Diagram of the Interplanetary Flight of the Craft Mars-2 and Mars-3. 1, 2, 3, Trajectory correction; 4, division of the descent vehicle of the orbital craft; 5, braking of the craft and transition into orbit as a satellite of Mars.

The orbital compartment of the Mars-3 spacecraft went into the orbit of an artificial satellite of Mars at a minimum distance of 1,500 km from the planet's surface and a maximum distance greater than 200,000 km. The complex investigations of the properties of the surface and atmosphere of Mars with respect to the nature of the emission in the visible, infrared, and ultraviolet regions of the spectrum, and also in the radio region, were carried out for more than 8 months during the spacecraft's flight around Mars. 11 scientific experiments were conducted onboard the spacecraft. 7 of them are associated with the investigation of the planet itself, 3 of them with measurements of parameters of the interplanetary medium, and 1, carried out cooperatively with French scientists, with the investigation of the Sun's radio emission. The most important data were, of course, obtained about the planet itself. Among these data are measurements of the temperature of the surface and soil of Mars, the investigation of its relief, and the composition and structure of its atmosphere. These matters will be discussed in detail in the next sections of this chapter.

Almost all the instruments mounted onboard the spacecraft were oriented in such a way that, upon the passage through its pericenter with a speed of 4 km/sec (minimum distance from the surface), they were "watching" the planet, distinguishing sections on the surface with a size of from 6 to 50 km. From the Earth it is possible to make analogous observations with the help of optical telescopes regions 500-1,000 km in size, and ground-based radiotelescopes receive radiation of the entire disk of the planet at once.

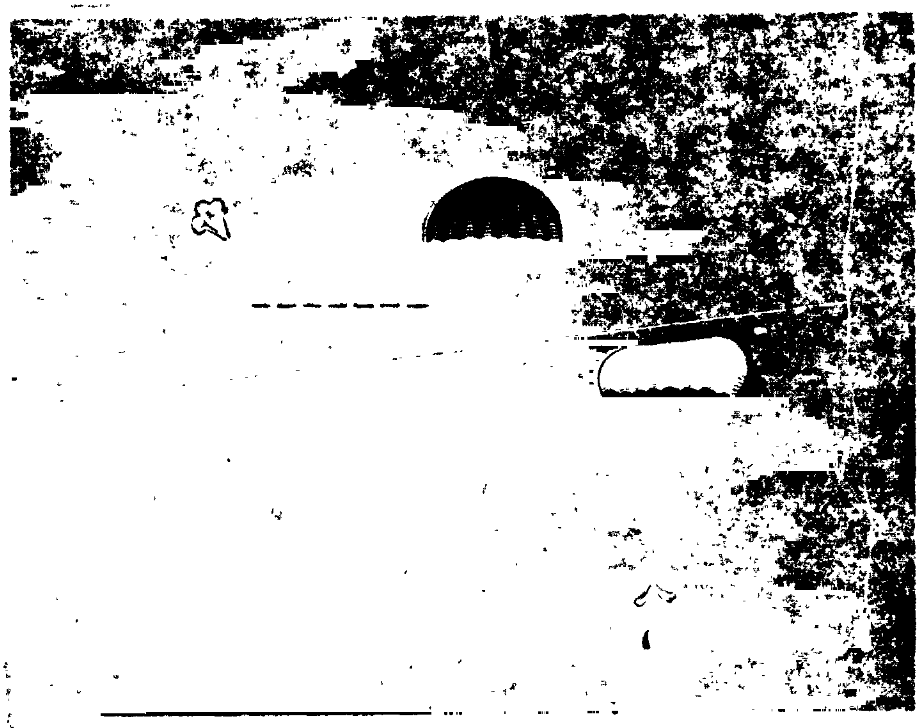

Figure 12. Schematic Diagram of the Landing of the Mars-3 Descent Capsule: 1, Separation of the descent capsule; 2, Ignition of the descent capsule's motor; 3, Aerodynamic braking; 4, Descent by parachute; 5, Ignition of the soft landing motor and jettisoning of the parachute; 6, Descent capsule on the surface of Mars in operating position.

An auxiliary role, associated mainly with providing a tie-in of the measurement results in other spectral intervals, was assigned to photography of the planet in the complex of experiments carried out on the spacecraft. Moreover the photographs taken by Mars-3 from large distances permitted refining the optical flattening of the planet (as distinguished from the dynamical flattening), constructing profiles of the relief based on the image of the edge of the disk for sections of large extent, and obtaining color images of the disk of Mars by means of the synthesis of photographic images made with different light filters. Interesting twilight phenomena, in particular the illumination of the atmosphere approximately 200 km beyond the terminator line (the boundary between night and day) and measurement of the color of the surface near the terminator, were detected on the photographs obtained. A layered structure of the Martian atmosphere is traced in several photographs.

Let us briefly discuss the construction peculiarities of the spacecraft and the most complex and important problems associated with the basic stages of the flight.

The spacecraft are equipped (Figure 13) with systems for automatic control and orientation, radio control, trajectory measurements and the transmission of information, automatic equipment, energy supply, thermal regulation, onboard radio instrumentation, a time-programming instrument, a motor assembly, and a complex of scientific instrumentation. /52

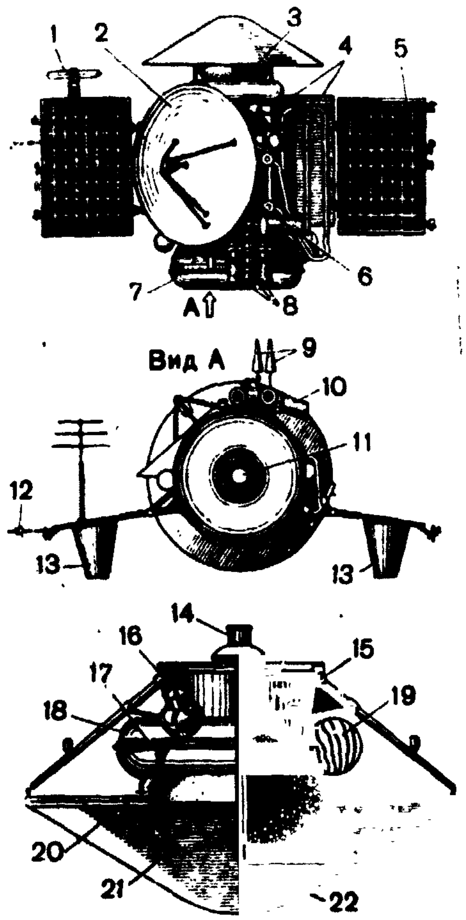

Figure 13. Mars-3 Automatic Interplanetary Spacecraft. Schematic diagram of the automatic spacecraft (above) and the spacecraft's descent capsule (below): 1, Antenna of the "stereo" scientific instrumentation; 2, Parabolic highly directional antenna; 3, Descent capsule; 4, Radiators of the thermal regulation system; 5, Solar battery panel; 6, Tank unit of the motor assembly; 7, Instrument compartment; 8, Optical-electronic instrumentation of the star orientation system; 9, Antenna of low directionality; 10, Optical-electronic instrument of the automatic navigation system; 11, Correcting and braking motor; 12, Magnetometer; 13, Antennas for the link with the descent capsule; 14, Separation motor for the descent capsule; 15, Instruments and equipment of the automatic control system; 16, Parachute deployment motor; 17, Antennas for the link with the orbital station; 18, Parachute container; 19, Main parachute; 20, Radio altimeter antenna; 21, Aerodynamic braking housing; 22, Automatic Martian station.

The instrument compartment is intended to accomodate the spacecraft's onboard systems and to protect them from the long-term effects of exposure to space conditions. On the outside of the compartment are arranged optical-electronic instruments of the system for tracking the Sun, Earth, and a star and of the automatic navigation system along with the scientific instrumentation.

The instrument compartment is connected with the tank unit of the motor assembly, which serves as the main support unit of the spacecraft. The motor assembly is located in the lower part of this unit. Above there is an adapter for attaching the descent stage. Two solar battery panels consisting of silicon light converters, a highly directional parabolic antenna, and antennas of low directionality are suspended from the tank unit. Radiators of the thermal regulation system are attached on one of the braces of the solar battery panel bracket. On the same panels are mounted part of the scientific instrumentation, two antennas to provide a radio link of the orbital station with the descent stage, an antenna for carrying out the Soviet-French "stereo" experiment, and the little motors of the orientation and stabilization system. /53

The descent stage is an independent Martian station. It is equipped with systems and instrumentation which provide for the device's separation from the orbital station, its transition to an approach trajectory with the planet, braking, descent in the atmosphere, and a soft landing on the surface. The device consists of an instrument-parachute container, an aerodynamic braking housing, and a connecting frame. A solid-fuel motor for the transition of the separated device from a fly-by to an impact trajectory and aggregates of an automatic control system for stabilizing the device after its casting off from the orbital compartment are housed on the frame.

The instrument-parachute container is made in the form of a torus. It is mounted in the upper part of the descent stage and is connected to it with the help of coupling straps. Inside the container are arranged the pilot and main parachutes. The motor for extracting the parachute, the braking motor assembly for soft landing and the parachute jettisoning motor, the radio altimeter antennas, the antennas for the link-up with the orbital station, and scientific instrumentation are mounted in the container. The cone-shaped braking shield serves for the aerodynamic braking of the descent stage in the atmosphe of Mars and for its protection from the high temperatures arising during the descent.

A hermetic instrument compartment is located inside the automatic Martian station. Instrumentation for the automatic control system, the radiocommunication unit and telemetry, and the scientific instrument unit, including the television panorama attachment, are located in it. On the outside are mounted the scientific instruments with the mechanisms for their deployment, the radio unit's antennas, and the systems for putting the station into its working configuration after the landing. The necessary sequencing of the operation of the systems was provided by a time-programming unit.

Prior to the flight the elements of construction and the scientific instrumentation of the spacecraft's descent stage were subjected to sterilization in order to prevent the transport of terrestrial microorganisms to the surface of Mars.

The control system includes an orientation system, a gyroscopic instrument to stabilize the spacecraft in space (a gyro-stabilized platform), an onboard digital computer unit, and an automatic space navigation system.

The orientation system goes into operation from the instant of the spacecraft's separation from the launch rocket and functions during the entire course of the flight. The optical-electronic instruments determine the position of the spacecraft relative to the Sun, and, with the help of small gas reaction motors, the spacecraft is oriented in space in such a way as to provide for the normal functioning of the thermal regulation system, the energy supply system, and so forth.

As the distance between the Earth and the spacecraft increases, the orientation system, which simultaneously tracks the Sun and a star (Canopus), changes /54 the spacecraft to a position in which the highly directional antenna of the onboard radio unit is oriented towards the Earth. The conditions for orientation of the remaining systems of the spacecraft are practically unchanged. Such a method of constant solar-stellar orientation has been applied for the first time on interplanetary spacecraft.

In carrying out the first two corrections, data concerning the size and direction of the impulse of the motor's thrust necessary to carry out these maneuvers are transmitted from the Earth to the onboard digital computer over the radio link. Information from the gyro-stabilized platform concerning the spacecraft's position in space also enters the computer. The computer processes this data and gives the commands to turn the spacecraft and to switch the engine on and off, and the automatic control systems carry out these operations.

It is necessary upon the approach flight to know first of all the position of the spacecraft relative to the planet. But the spacecraft's position at this time, which is determined from data of the trajectory measurements with the help of ground-based radar devices and the positions of Mars, are not known accurately enough. Therefore in order to carry out the basic goals of the flight, namely, the injection of the spacecraft into the specified orbits of artificial satellites of Mars and to provide the conditions required for the entry into the planet's atmosphere of the descent stage, an automatic space navigation system is used. This system permits correcting the spacecraft's trajectory as necessary for its approach flight to the planet.

The optical-electronic instrument determines the actual position of the spacecraft relative to Mars, and it transmits the results of the corresponding measurements to the digital computer for subsequent processing. Its spatial orientation is determined onboard the spacecraft, and the time of the motor's operation in order to carry out the third trajectory correction is calculated.

After carrying out the maneuver, the separation of the descent stage takes place, and with the help of its own automatic control system the necessary control of its motion is provided for the descent stage's entry into the atmosphere of Mars at a specified angle, which is the determining condition condition for a successful soft landing.

A certain time after the descent stage's separation, the braking motor on the station is turned on, and it transfers from a fly-by trajectory to the orbit of an artificial satellite of Mars.

The onboard radio unit, together with the corresponding instrumentation of the ground-based command-measuring stations, permits making trajectory measurements, carrying out the reception of commands for control by the station's systems, conducting the transmission of telemetry and video information and the reception and recording of data arriving from the descent stage for their subsequent transmission to the Earth.

Two radio channels, one narrow-band and the other wide-band, are used for the orbital station's link with the Earth. The narrow-band channel is intended mainly for carrying out trajectory measurements and for the transmission of telemetry information. It operates in the decimeter region of the radio spectrum. The wide-band radio channel, which uses centimeter waves, permits transmitting large volumes of information from the television equipment and the scientific instruments. /55

The radio link with the stations was maintained during the transfer flight and in orbit by the systems with antennas of low directionality, and, when the spacecraft were accurately oriented towards the Earth, the radio link was maintained through the highly directional parabolic antennas.

The volume of information to be transmitted over a radio link depends significantly on the distance between the transmitting and receiving devices. The orbital station is tens of thousands of times nearer the descent stage than is the Earth. Therefore an extremely advantageous method is used on Mars-3 to transmit signals from the descent stage to the Earth by means of their retransmission through the orbital station located in orbit of a satellite of Mars. This method permits the elimination on the descent stage of complicated (heavy) directional antennas and powerful transmitters and power supplies and the use of a light radio instrument. The onboard radio devices of the orbital stations serve to transmit information to the Earth.

It is important to note that the problems of radio control of spacecraft at interplanetary distances are associated with a number of peculiarities and difficulties. It should be taken into account that the time for the passage of each radio command and the confirmation of its execution occupies several minutes. This time of transmission continually increases with the distance of the spacecraft from the Earth.

The energy supply system for providing electrical energy to the onboard instrumentation includes a generator, for which a solar battery is used, and chemical sources of current consisting of the buffer battery in the orbital compartment and an automatic battery in the descent stage. During the entire flight solar energy provided for the charging of the buffer battery and the supply of the onboard instrumentation operating in the intervals between the communication sessions. The supply of the onboard instrumentation during the radiocommunication sessions was accomplished from the onboard battery. The independent battery of the descent stage was charged prior to the separation of the descent stage.

The automatic equipment system of the spacecraft is intended to control the onboard systems while they carry out the flight programs to the planet Mars. It carried out the reception and analysis of signals necessary for coordination of the operation of the spacecraft's systems, the logical processing of information obtained, and the transformation of it into useful commands for control according to the assigned program.

The thermal regulation system maintained the temperature of the spacecraft's onboard systems and equipment within specified limits. On the orbital device it consisted of screen-vacuum heat isolation, special thermal regulation coverings. and active circulating gas systems of the closed type with a radiator-heater constantly directed at the Sun and a radiator-cooler oriented towards outer space. The gas which fills the instrument compartment serves as the coolant. /56
The continuous circulation of the coolant was provided by a ventilation device.

The thermal regulation system of the descent stage of the Mars-3 spacecraft included screen-vacuum heat isolation, a radiation heater with a surface regulated as a function of the temperature inside the device, and an electrical heater.

The restartable motor assembly provided for correction of the spacecraft's trajectory during the transfer flight and its braking upon its transition to the orbit of an artificial satellite of Mars. It consisted of a liquid reactive motor with a pump system for supplying the fuel components, control elements, and a fuel tank assembly.

One of the main problems of the flight was the carrying out of a complicated scientific-engineering experiment, namely, the landing of the descent stage of the Mars-3 spacecraft on the planet's surface.

Its solution was complicated by the fact that the atmosphere of Mars is very rarefied, and data about its composition and density are insufficiently reliable. Strong winds are possible on the planet. In addition the relief of the Martian surface has not been studied very thoroughly, and the nature of its soil is almost unknown.

The designs of the aerodynamic cone, parachutes, and the soft landing motor were selected on the basis of the conditions of minimum weight and their reliable operation under a wide range of possible descent conditions and the characteristics of the Martian atmosphere. Notwithstanding the fact that the atmosphere of Mars is rarefied, a device entering it with a speed of 6 km per second is strongly heated. Due to the light and reliable thermal protective coverings, the device survived this experience.

The landing process started after the accomplishment of the third correction and the separation of the descent stage from the spacecraft. Separation occurred on December 2 at 12 hours, 14 minutes. After 15 minutes the descent stage's motor was turned on, and it provided for the transition of the descent stage into an encounter trajectory with the planet. Then a turn of the descent stage was carried out to provide the necessary angle of attack during its entry into the atmosphere.

At 16 hours, 44 minutes, Moscow time, the descent stage entered the planet's atmosphere at an angle close to the calculated one, and aerodynamic braking began. Stability of motion during this portion of the flight was provided by the aerodynamic shape of the descent stage. The descent in the atmosphere to the surface of Mars lasted not much more than 3 minutes.

At the end of the braking portion of the descent, deployment of the pilot parachute and then the main parachute was accomplished with the help of a gunpowder motor upon command from an overload detector while the descent stage was still moving at supersonic speed.

When the descent stage was decelerated to nearly sonic speed, reefing, the complete opening of the main parachute's cupola, was carried out on signals from the time-programming mechanism. Simultaneously the aerodynamic housing was jetisoned, and the radio altimeter antennas of the soft landing system were opened. / an altitude of 20-30 meters the braking soft-landing motor and the time-programming device setting the sequence of operations associated with the operation of the automatic Martian station on the planet's surface were turned on by command of the radio altimeter. At this time the parachute was taken off /57
to one side by another reactive motor as that the coupla would not cover the station. At the instant of the landing, the special shock-absorbing covering reliably protected the device from possible damages.

The descent in the atmosphere to the surface of Mars lasted little more than 3 minutes. The device completed its landing at a point with the areographic coordinates 45° S and 158° W.

One and one-half minutes after the landing, the independent Martian station was put into operation condition by signals from the time-programming device, and at 16 hours, 50 minutes, 35 seconds, the transmission of a video signal from the planet's surface began. The appearance of the signal from the descent stage at the calculated time was recorded by special detectors in the orbital station's receiving devices. Simultaneously the recording of the video signal began on two recording devices of the Mars-3 spacecraft. The received image was transmitted from the orbital station to Earth in the subsequent communication sessions.

Very valuable data about the mysterious planet were obtained as a result of the many-months of successful functioning of the Soviet artificial satellites of Mars.

The flight of automatic interplanetary spacecraft placed into orbit as artificial satellites of Mars, the first soft landing on its surface in the history of cosmonautics, the complex scientific investigations of the planet and the surrounding outer space, and the solution of the most complicated engineering problems of the automatic navigation and control of the flight of automatic spacecraft at significant distances from the Earth — all these accomplishments clearly indicate that Soviet science and engineering have achieved a remarkable success. This prominent event in Soviet cosmonautics opens up wide perspectives for the subsequent investigation of planets of the Solar System with the help of automatic devices.

The world scientific community has highly valued this unprecedented expedition of Martian robots. The prominent English scientist, Director of the Jodrell Bank Astrophysical Observatory, Professor Bernard Lovell, wrote that it is impossible to overestimate the significance of this new exploit of Soviet science. It opens up in the full sense of the word a new era in the investigation of outer space. Is this not fantastic, and is such swift progress not evidence of the fact that science and engineering have entered a period in which it seems that nothing is impossible for them?

What new information about Mars have the automatic messengers communicated to us?

The Surface of Mars

Let us first discuss the main results of observations from the Earth. In the case of observation from the Earth with the help of optical methods, the Martian surface (whose area is 2.7 times smaller than the area of the Earth's /58 surface) looks comparatively smooth. Regions of three colors are distinguished: orange-red regions surrounding dark spots and the named continents, dark regions which have acquired the designations "seas", "lakes", "bays", and "swamps", and the snow-white formations at the planet's poles which are called "polar caps" by analogy with the terrestrial poles.

Since the colorations of the bright and dark regions are stable, this permitted compiling a map of the Martian surface. It is evident on this map that the continents occupy approximately 5/6 of its surface area. The dark regions consist of individual spots and are located mainly in the equatorial belt. They periodically change their color with a change of the seasons. They darken in the spring and summer, taking on more distinct colorations, and in the fall and winter they fade, and their boundaries become indistinct.

Radar and spectroscopic observations have shown that height differentials exceeding 10 km occur on the surface of Mars. We note that the radar methods permit recording the exact times of the transmission and reception of the pulse (reflected from the planet) with an accuracy which corresponds approximately to a kilometer height on the surface of Mars.

Spectroscopic measurements of the surface relief are based on a determination of the amount of gas in the line of sight above various regions of the surface. Taking into account the fact that it is larger in depressions than on elevated heights, it becomes possible to determine the differences in height.

The rocks covering the Martian surface are similar to a hydrate of iron oxide, the so-called limonite. It has an orangish-brown color and is easily melted. Upon decomposition limonite breaks up into red iron ore and water. 5-6% of this material is sufficient to impart a rusty or red color to sands and clays. Perhaps here is the reason for the origin of the planet's color?!

What scientists have seen on photographs of Mars has fundamentally altered their concept of its surface. It is not so smooth and largely resembles the Lunar landscape: the same uneven surface, pockmarked with craters, the same uninviting and barren appearance. Investigators have distinguished three types of Martian surface on the basis of their structure: regions filled with craters, regions with chaotic structures, and regions devoid of characteristic features. On the majority of the photographs, the surface belongs to the cratered type of terrain. The craters are of the most varied diameters, from 500 m up to 800 km. The investigators assume that the large craters were formed by the collision of the planet with asteroids. Craters of smaller sizes and more recent origin are visible on the bottom of the larger craters. Talus, and also terraces similar to the terraces in the Lunar craters Copernicus and Aristarchus are noticeable in some Martian craters. However, on the whole, Martian craters are not similar to Lunar craters. They are raised up above the surrounding terrain to a lesser degree, and their edges are smoother, which the investigators ascribe to the effect of erosion. Evidently, Martian /59 craters have undergone significantly greater evolution than Lunar craters; investigators assume the main mechanism for it to be landslides, i.e., the shifting of minerals too heavy to remain in place under the action of the wind. Thus the distinction of the Martian craters from the Lunar craters is explained not only by different processes of their evolution but also by a difference of the materials forming the surface of Mars. A continuous transition in the sizes of craters has not been detected on the photograph, which significantly distinguishes the Martian from the Lunar craters. A possible cause for this peculiarity is the weathering and transport of soil particles. Another important peculiarity of the Martian surface relief is its smoothness and nonuniformity (the transition from regions with a large number of craters to a region where there are almost no craters). For example, there is the Hellas region, in which no clearly expressed relief elements have appeared in an area of about 570,000 km^2. One can assume that the structureless zones on Mars are the analog of terrestrial deserts. The chaotic type of surface is characterized by sharply broken relief (mountain rigids and valleys of short length, cliffs, fissures with abrupt slopes, and so forth), and there are no similar regions either on the Earth or on the Moon.

Mariner-7 transmitted literally fantastic pictures of the southern pole of Mars covered by mysterious crater formations reminescent of snowslides or glaciers on Earth. The locality of the southern pole is, in comparison with all the regions of Mars which have been photographed, the most rugged: deep "valleys", a high mountain ridge, and also formations reminescent of terrestrial glaciers and slides are visible on the photographs. The southern polar cap was photographed from 60° south latitude to the pole. The relief details here are easier to see, and therefore there are significantly more craters. Not only the smallest craters, but also protruding relief forms are visible.

And so Mars, which was assumed, in contrast to the Earth and the Moon, to be a planet with a very level, smooth, and gentle relief without noticeable mountains and prominences (with the exception of the well-known Mitchell mountains at the south pole), unexpectedly turned out to be mountainous and very rugged.

The tracks of the spacecraft's flight near the planet began in the southern hemisphere, where summer was coming to an end at this time, then crossed the equator, and concluded in the northern hemisphere. The initial points of the tracks occurred in regions where it was still morning, and the final tracks occurred at the midday, evening, and sometimes even the nighttime hours.

The temperature of the surface of Mars was measured by infrared radiometers. These instruments recorded the thermal emission of those regions of the planet which were photographed at the given instant by the television cameras. According to the readings of the radiometer of Mariner-6, the temperature of the planet's surface varies from +16°C at noon to -102°C on the nighttime side; dark regions have a higher temperature in comparison with the bright regions. The recorded rate of cooling is comparatively small. This fact gives reasons for assuming that the surface layer of Mars ha higher thermal insulating proper- /60
ties than the Earth's surface.

On the basis of the data of the Mars-2 and Mars-3 automatic interplanetary stations, the surface temperature along the ground tracks varied within wide ranges; from +13°C at 14 hours local solar time (11° south latitude) to -93°C (19 hours local time (19° north latitude). But the temperature fell to -111°C in the vicinity of the north polar cap. It is very important to know the temperature on the surface of Mars at various latitudes and at various times. In the first place, it is necessary because this is one of the main climatic characteristics, and in the second place one can assess the properties of the material of which the soil consists on the basis of the temperature variations during the day and from place to place. The low nighttime temperatures indicate that the surface of Mars very rapidly cools off after sunset and, consequently, the thermal conductivity of the soil is low. Quantitative estimates show that it corresponds to dry sand or dry dust in a rarefied atmosphere. The Martian "seas" (dark regions) turn out on the average to be warmer than the "continents" (bright regions). The difference in temperatures, which reach 10°, is explained by the fact that the seas (maria) have a low reflectivity, absorb more solar energy, and are heated up more. In individual cases the darker maria regions cool off more slowly after sunset and, consequently, have soil of greater thermal conductivity.

It is very interesting that a region was detected on the nighttime side of the planet where the temperature was 20-25° higher than in the surrounding regions. The cause for this phenomenon is still not clear.

The soil temperature was measured to a depth of 30-50 cm with the help of the onboard radiotelescope. It turned out that it does not undergo the diurnal oscillations, which indicates a large thermal inertia and a low thermal conductivity for the soil. Besides the temperature, the di-electric constant, a quantity which depends mainly on the soil density, was also determined. The measurements showed that the variation in the soil temperature and di-electric constant are related, i.e., large temperature values of individual regions correspond to large values of the di-electric constant. This result indicates that the soil density varies along the ground track of the measurements.

Martian Canals

The Italian scientist A. Secchi called attention for the first time in 1859 to the geometrically regular strikes covering the surface of Mars like a net. G. Schiaparelli, a countryman of A. Secchi, who had observed Mars during its great opposition of 1877, confirmed their presence. A long time passed after this memorable event, and a lively argument went on and on as to the origin of these puzzling features. Canals are a grandiose artificial irrigation system created by rational creatures populating Mars and intended to distribute /61 the scarce water reserves the planet — so declared P. Lowell!

Not so! asserts Catterfeld. The canals are nothing more than lines of tectonic fractures of the planet's crust produced by an irregularity of its rotation. Water progresses along these fractures, nourishing an abundant vegetation. A third group argues that the canals are strips of vegetation, and a fourth group assumes that they are crevices in the icy envelope of Mars. In general so many hypotheses, conjectures, and sometimes outspoken speculations have been advanced that we have no idea concerning their contents.

The photographs transmitted from the automatic interplanetary stations /62 have still not given a clear answer to this question. Suggestions have been advanced on the basis of these photographs that the lines forming a network on the surface of Mars are salts, fissures, crater chains, ridges, and other relief forms perceived as continuous features of heightened contrasts.

Some of the famous Martian "canals" are visible on the "distant" photographs of Mars taken from a distance of about 1.5 million km as well as they are in the case of the best observations from the Earth. A slightly curved mountain ridge, 160 km in width and about 1,100 km in length without noticeably apparent edges, appeared in place of the broad and dark Agatademon canal on the "near" photographs (from a distance of 4-3.5 thousand km). As the result of analysis of the photographs, it has turned out that this feature is a broad, slightly curved ridge mottled with craters and canyons resembling the edge of a gigantic crater. On a photograph taken by the Mariner-9 spacecraft, there is a smooth plateau (Figure 14) cut through by large tectonic trenches which could also be taken as a canal as seen through terrestrial telescopes.

The Atmosphere of Mars

Investigation of the gaseous envelope of Mars constitutes a very difficult problem in the resolution of which some successes have only recently been achieved after a long period of failures and mistakes. Prior to the flight of automatic interplanetary spacecraft to Mars many models were constructed of its atmosphere. The majority of them were based on the assumption that its atmosphere is an analog of the terrestrial atmosphere. Notwithstanding the fact that spectroscopically only carbon dioxide gas had been detected in the composition of the

Martian atmosphere up to 1956, the majority of astronomers were inclined to the opinion that the main constituent of the Martian atmosphere is nitrogen with insignificant admixtures of carbon dioxide, oxygen, and water vapor.

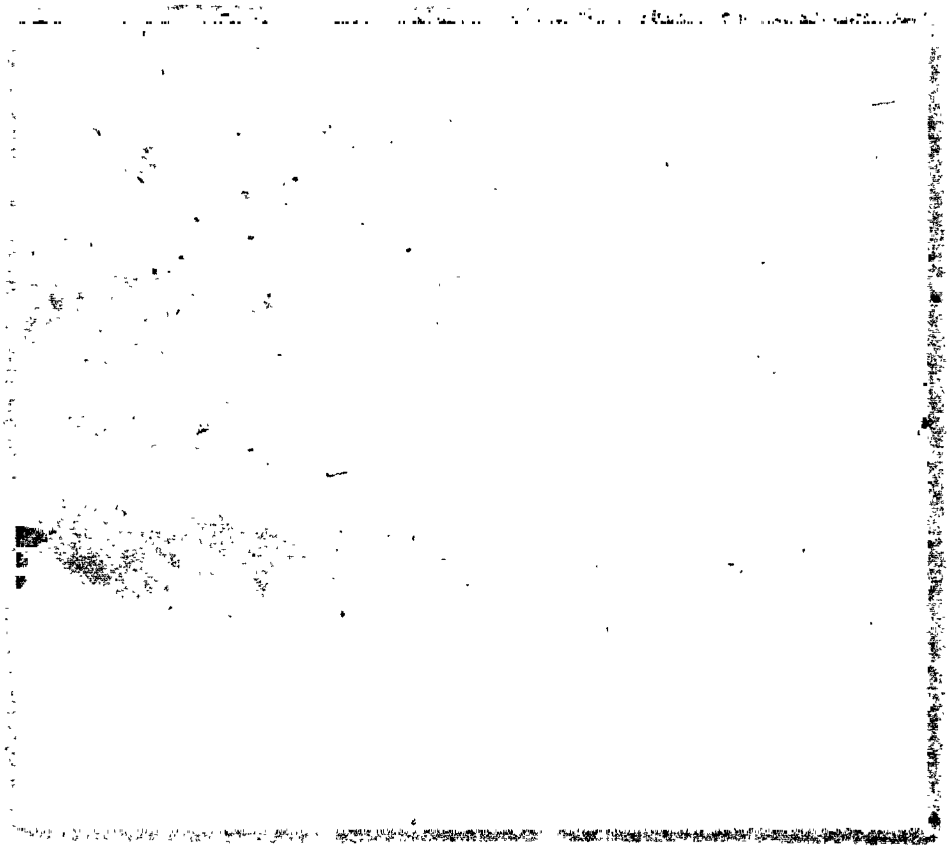

Figure 14. Photo of a Portion of the Martian Surface 325 × 400 km, Located 480 km South of the Equator, on the South-eastern Edge of the Vast Illuminated Elevation Arcadia-Tractus-Albus. The photo was taken from an altitude of 2,000 km. The level plateau is bisected by a sharp tectonic chasm. When observed through telescopes on Earth, this pit can seem to be a straight line and can be mistaken for a canal.

During the 1963 opposition of Mars, traces of water vapor were detected in its atmosphere for the first time, the abundance of CO_2 was also established, and the surface pressure, which turned out to be approximately 20 millibars, was determined. A low oxygen and ozone content, as well as an insignificant amount of water vapor, was established with the help of the spectral method. This was a sensation for astronomers. In fact nitrogen in an atmosphere is produced mainly by volcanic eruptions, and its absence in the atmosphere of Mars may indicate the absence of volcanic activity.

The escape velocity for Mars is comparatively low — 5 km per second. Due to this fact it cannot retain the light gases and has a very rarefied atmosphere which is very transparent. At altitudes from 1 to 30 km, a blue haze about 20 km in thickness is observed. Evidently the haze layer originated due to the formation of oxides under the influence of solar ultraviolet radiation. In addition yellow clouds moving at a speed of 10-40 m per second, which are assumed to be dust storms, are noticed in the Martian atmosphere. They significantly impair /63 visibility of the surface of Mars. Mars' gravity, insignificant in comparison to Earth's, is responsible for one very significant peculiarity in the structure of the Martian atmosphere. As altitude increases, its density drops far more slowly than in the terrestrial atmosphere. Thus, for example, pressure in the terrestrial atmosphere reaches one-tenth of the surface value at an altitude of 16-17 km, but on Mars a one-tenth decrease in pressure occurs only by an altitude on the order of 30 km. This results in the fact that the pressure at this altitude above the planet's surface is the same as in the Earth's atmosphere at the same altitude. Calculations show that the density in the atmospheres of the Earth and Mars are comparable at an altitude on the order of 40 km, and at still greater altitudes the pressure in the Martian atmosphere exceeds that of the terrestrial atmosphere. This distinction results in the fact that meteors burn up in the Martian atmosphere at an altitude on the order of 200-250 km, but at an altitude of 120-150 km in the terrestrial atmosphere. However, the danger of serious overheating of the housing of spacecraft entering the Martian atmosphere is less than in the case of entry into the terrestrial atmosphere in view of the lower accelerating attraction on Mars. For this reason Martian dust storms, which astronomers have repeatedly observed, should be more powerful than terrestrial storms, since enormous masses of dust-like material are maintained there for an extended time under the influence of the wind rushing rapidly upwards. Investigations of the planet Mars during the period of its great opposition of 1971 have clearly confirmed this. Here is what the President of the Planetary Physics Commission of the USSR Academy of Sciences Astronomical Council, Professor I. K. Koval', has to say on this question. In the second half of September, the transparency of the Martian atmosphere sharply decreased due to the rising dust storms which for several days covered the dark features of the surface almost over the entire visible disk. But what caused it? The activity of volcanoes or a flux of meteoric particles exploding into the atmosphere of Mars? Such phenomena are not able to obscure a planet's disk. Those scientists are evidently on the correct path who assume that this phenomenon is associated with storms. The winds there are stronger, and they exceed the velocity of air currents on the Earth and are able to blow fine particles away from the planet's surface, carrying them to high altitudes. Scientists have encountered a high degree of dustiness of the planet's atmosphere at other great oppositions (1924, 1939, and 1956). Especially pronounced obscurations were observed during the great opposition of 1956, when the transparency coefficient of the atmosphere decreased by a factor of 3, and even the complete disappearance of the southern polar cap was noticed.

When the Mars-2 and Mars-3 spacecraft went into orbit around Mars, a dust storm was raging on it. For two months the entire planet was obscured by dense clouds of dust raised from the surface. The dust storm significantly hindered photography of the planet and some scientific measurements. However, images of the disk of Mars obtained with the help of the photographic instrumentation /64 significantly added to information about Mars. For the first time Mars was photographed at phases not observable from the Earth. The images transmitted from onboard the spacecraft filled in information about the surface, the structure of the atmosphere, and the planet's shape. The measurements carried out showed that the altitude of these clouds is about 10 km above the mean surface level. The cloud layer was thinner above higher regions and thicker above lower regions. The dust storms on Mars are a powerful and as yet puzzling phenomenon. The usually transparent atmosphere of Mars suddenly becomes in a few days almost as opaque to visible radiation as the cloudy atmosphere of Venus. But as measurements have shown, the transparency improves as one goes to longer wavelengths. This indicates a significant fraction of very fine dust particles (with a size of about one micron) in the clouds. Such particles should settle out very slowly, which agrees with the total duration of the dust storm. However, the Mariner-9 photographs showed a rapid increase in transparency at the end of December. It was incomplete, but the visibility improved significantly in ten days. In order to explain this, it is necessary to assume the presence in the clouds of a certain fraction of rapidly settling particles of comparatively large size. In general particles of various sizes were evidently contained in the Martian clouds during the period of the storm, and their ratio varied with time. Much data indicates, in some way or other, an increase of transparency with wavelengths. Such clouds should cool the surface and increase the atmosphere's temperature, which was actually observed. A unique "reverse hot-house effect" was created, opposite to the situation produced on Venus in which the atmosphere is heated up due to its opacity to infrared radiation.

Of what does the cause of such strong winds consist? The atmosphere of Mars is very rarefied and transparent, as has already been stated. In the daytime the Sun strongly heats up the planet's surface, and at night Mars rapidly cools off. These sharp variations result in a large pressure differential, which causes such strong winds that, by comparison, terrestrial storms can be assumed to be a light breeze. This is one side of the answer to the question.

Another cause probably consists of the fact that during the great oppositions of Mars the planet is located at the perihelion of its orbit; therefore the Sun heats up the Martian surface more strongly, and thus the temperature differential is much larger than during other oppositions.

The observed clouds in the Martian atmosphere are separated on the basis of color into yellow, blue, and white clouds. The yellow clouds appear in the lower layers of the atmosphere at an altitude of approximately 5 km and lower. They probably consist of fine dust of, for example, iron oxide hydrate particles.

The blue clouds (violet haze) are observed at higher altitudes near the terminator line on the morning and evening edges of the disk. Taking into account the atmosphere's chemical composition and the most probable dependence of the temperature and pressure variation with altitude, one can assume that these clouds form ice crystals. /65

The white clouds are evidently of the same nature as the blue ones, but they consist of larger ice crystals. These clouds are frequently situated above the bright regions near their boundaries with the dark regions.

Laminar flows predominate in the atmosphere's circulation. In the spring the direction of motion of the clouds is predominantly westward, and in the summer — eastward. In springtime the formation of clouds is associated with the melting of the polar caps, and in the summer — with processes in the dark regions. Morning and evening fogs of low density are often observed.

Measurements with infrared spectrometers in the region of the planet's reflected (1.9-6 μ) and intrinsic (4-14.7 μ) radiation have permitted derivation of some information about the composition of the lower atmosphere of Mars. In particular, absorption bands of solid carbon dioxide and ice have been recorded. Taking into account the temperature measurement data, one can suggest that ice crystals are found in the form of fog in the atmosphere in equatorial regions, and carbon dioxide is found at the surface in the polar regions. The infrared radiometer of Mariner-7 recorded a minimum temperature of -160°C at the southern polar cap and an average temperature of -118°C, which corresponds approximately to the freezing temperature of carbon dioxide at the atmospheric pressure existing at the surface of Mars. The atmospheric pressure at the surface has been successfully established in different areas by the radio transmission method. Thus as Mariner-6 set behind the planet's disk, the radio transmission showed that the atmospheric pressure at the surface was 6.5 millibars in the vicinity of the meridian of Sinus.

Let us recall in this connection that the pressure in the Earth's atmosphere at sea level is equal to 1,013 millibars. Taking into account the fact that a minimum surface pressure of 3.5 millibars and a maximum of 9 millibars has been recorded, and taking the nature of the surface relief into consideration, one can assume with sufficient justification that the mean surface level has a pressure of 6 millibars.

The infrared photometers of the Mars-2 and Mars-3 spacecraft showed that the pressure on Mars is 5.5-6 millibars (about 4-4.5 mm of mercury) at the mean level, which is approximately 200 times less than on the Earth.

The water vapor content did not exceed 5 μ of precipitable water, which is a thousand times less than in the terrestrial atmosphere. If all the water contained in the Martian atmosphere were to be uniformly distributed over its surface, it would form a layer slightly thinner than a human hair. Near the surface the atmosphere consists mainly of carbon dioxide gas. At an altitude of about 100 km, the carbon dioxide gas is broken down under the influence of solar ultraviolet radiation into a molecule of carbon monoxide gas and an oxygen atom. Such a decay process for water vapor results in the appearance of hydrogen atoms. Therefore at altitudes of 300-400 km the atmosphere becomes mainly atomic /66
hydrogen. Traces of oxygen are observed right up to an altitude of 700-800 km.

The temperature of the upper atmosphere in the altitude range from 100 to 200 km increases and becomes constant higher up. This is approximately the picture observed in the upper atmospheres of the Earth and Venus. Strange as it seems, the upper atmosphere of Mars is more similar to the upper atmosphere of Venus than to that of the Earth.

Martian Days

Observing the disk of Mars through a telescope for a sufficiently long time, for example, for an entire night, one notices how the details of its surface appear one after the other from behind the disk, gradually move towards the opposite edge, and then disappear. It is clear that this occurs due to the rotation of Mars, which is similar to the diurnal rotation of the terrestrial sphere and results in the succession of day and night. It has been determined from observations that the rotation period of Mars is 24 hours 37 minutes 23 seconds, which is 37 minutes 22.7 seconds longer than the Earth's rotation period. The latter indicates that Mars "lags behind" a complete revolution by 9° every terrestrial day, and a terrestrial observer sees a particular detail of the planet at the same position on the disk only after 40 days ($9° \times 40 = 360°$). Since the rotation period of Mars is similar to that of the Earth, it turns out that it is possible each night to inspect from the Earth one and the same hemisphere of Mars, which is only slowly and gradually replaced by the other. In order to inspect the surface of Mars completely during a day, it is necessary to carry out the observation at observatories located at various geographical longitudes. Thus, for example, if it is noon in Tashkent, and deep night reigns at the Mount Wilson Observatory (U.S.A.), then observing Mars from these observatories it is possible to inspect its entire surface during a day. The succession of day and night is accompanied by phenomena analogous to terrestrial ones. At intermediate latitudes the Sun rises and sets, moving at an angle to the horizon. Therefore the transition from one time of day to another is accompanied by twilights, when the surface is illuminated by oblique rays of a low-lying Sun. In the tropics and at the equator, the Sun rises and sets almost straight up. Here, just as at similar latitudes on Earth, day and night follow one another with an abrupt transition from light to darkness.

The Seasons on Mars

We know from our school classes in geography and astronomy that the succession of seasons on the Earth occurs not because the Earth approaches nearer to the Sun or moves further away from it, but due to the fact that the terrestrial equator is inclined to the plane of the Earth's orbit by an angle of 23.5°. It follows from this fact that the Earth's axis is arranged not perpendicularly but obliquely. As the Earth moves around the Sun, the direction of the Earth's axis /67 does not change. It is always directed with its north end towards the pole star. Therefore moving around the Sun, the Earth turns both its northern and its southern hemisphere to an observer.

An analogous picture occurs on Mars (see Figure 15). Opposite seasons occur simultaneously in its different hemispheres. When it is summer in the northern hemisphere, it is winter in the southern hemisphere. If it is fall in the northern hemisphere, then it is spring in the southern hemisphere. And this is because the inclination of the equator of Mars to the plane of its orbit is approximately the same as for the Ea... It is equal to 24°46'. This causes seasonal changes on Mars.

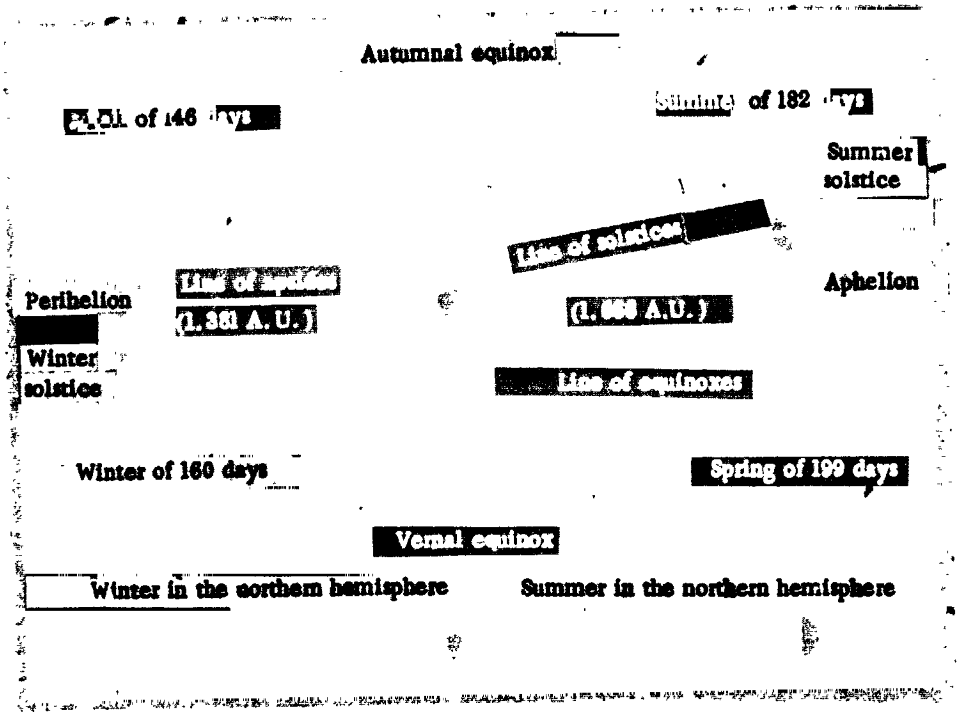

Figure 15. Seasons in the Northern Hemisphere of Mars.

It is well-known that the amount of heat falling on a given surface depends on the Sun's altitude above the horizon. The higher the Sun rises above the horizon, the stronger it heats. The fact that various thermal climatic belts occur on the Earth, such as the torrid (tropical), two temperate, and two cold belts, is explained by the different altitude of the Sun above the various localities of the terrestrial sphere. In addition, cold and warm seasons occur in each year. The same thing happens on Mars. Just as on the Earth, a distinct change of the times of the Martian year and the seasons occurs. A cold, severe /68 winter is followed by a cool spring, and then a warmer summer, which is replaced by a cool fall. After it the cold winter again begins with its short days and long nights. The results of such a change of seasons are easily visible through the telescope in the guise of the melting of the polar caps. However, the main difference there lies in the fact that the orbit of Mars is situated further from the Sun than that of the Earth, and its orbital motion is smaller than that of our planet. Therefore the annual path of Mars is longer. This results in the fact that the duration of a revolution of Mars around the Sun is almost twice as long as that of the Earth: it is 687 terrestrial days. A Martian year contains 669 of its own "Martian" days, which are somewhat longer than terrestrial days. Thus a Martian year is almost two (more exactly, 1.88) times longer than that of the Earth.

During the summer time (in July) for the northern hemisphere of the Earth, our planet is at its greatest distance from the Sun (152 million km), and in the winter time (January) it is at its smallest distance (147 million km). The difference of 5 million km is insignificant, and therefore summer in the northern and southern hemispheres are almost identically warm. The same thing can be said about the winter periods. But since the eccentricity of Mars is greater, its distance from the Sun at perihelion is 206.7 million km and at aphelion is 249.1 million km. Due to this fact, Mars receives one and one-half times less solar radiation at aphelion than at perihelion. Therefore the climate in the northern and southern hemispheres is very different. It is a pronounced continental climate. Even after a hot day on the equator, frosts occur at night. Mars passes through the perihelion half of its orbit more rapidly than through the aphelion half. Therefore summer in the southern hemisphere, which occurs during the perihelion period, is much shorter than in the northern hemisphere and warmer, and winter in the southern hemisphere is longer and more severe. Due to the significant eccentricity of the orbit of Mars, the duration of the seasons in the opposite hemispheres differs significantly (Table 4).

TABLE 4

Hemisphere		Duration of the Season			
Northern	Southern	Terrestrial Days		Martian Days	
Spring	Fall	199	381	194	371
Summer	Winter	182		177	
Fall	Spring	146	306	142	298
Winter	Summer	160		156	
		687		669	

The duration of day and night varies as a function of the season. In polar latitudes a lengthy day lasting almost an entire terrestrial year is replaced by a similarly long night. In the intermediate latitudes short winter days lengthen /69 with the approach of spring and summer and again decrease after the summer solstice.

The times of year on Mars are well traced by its polar caps.

Polar Caps

The northern and southern poles of Mars are covered by bright distinct features which are called "polar caps" by analogy with those of the Earth.

The white covering in the northern hemisphere towards the end of winter extends to latitudes of 50-60° and its diameter reaches 4,000-6,000 km, but in the summer it shrinks at a rate of 10-12 (sometimes as much as 100) km per day to a diameter of 700-1,500 km. The southern cap melts more rapidly, and it disappears completely in some years, which is explained by the eccentricity of the orbit of Mars. A dark collar forms around the melting cap, and the features adjacent to it acquire bright colorations; this wave of improving visibility moves towards the equator with a mean speed of 35 km per day, and towards the end of summer it even moves beyond the equator to 25° latitude in the other hemisphere. All of this is very similar to what occurs on the Earth. For example, observing the Earth for an extended time from the Moon, one would see a similar picture. A hypothesis has arisen completely naturally that the polar caps of Mars consist of snow or ice. However, this suggestion is not the only one possible. Several hypotheses have been advanced as to the nature of the polar caps.

Some scientists have assumed that this is a cloud cover or fog. Others have asserted that this is a salt covering, and they have pointed out as an example salt which forms extended bright coverings on the surface of terrestrial salt marshes. The majority of scientists have associated these caps with a layer of solid carbon dioxide — material which is well-known to all under the name of "dry ice". This hypothesis has received a comparatively wide distribution, since it corresponded to the data of spectral investigations with whose help the presence of carbon dioxide gas in the atmosphere of Mars was established.

What has amazed the scientists analyzing the photographs of the southern polar cap is the apparent thickness of the white covering, which attains 80 cm. They assume that this is almost certainly frozen carbon dioxide ("dry ice"), since there is not enough water in the atmosphere of Mars for such extensive deposits of snow or ice. They speak of the temperature variations in support of such an assumption. Thus the infrared radiometer of Mariner-7 recorded a minimum temperature of -160°C at the southern polar cap and an average temperature of -118°C, which corresponds approximately to the freezing temperature of carbon dioxide at the atmospheric pressure which exists at the surface of Mars.

However, it has been established on the basis of observations over many years from the Earth that the material of the polar caps does not completely disappear even when the temperatures are close to zero. Therefore the polar /70 caps most likely contain both solid carbon dioxide and a small amount of frozen water. The possibility has not been excluded that there is also ice under the polar caps (in a layer of permafrost).

Based on the Mars-3 data, the surface temperature of the northern polar cap is -110°C.

Observations of the southern polar cap from onboard the automatic spacecraft--satellites of Mars have shown that it does not melt away during the summer. This indicates that it cannot consist only of carbon dioxide. According to calculations, the rate of evaporation of carbon dioxide under the conditions of Martian summer is so high that towards the end of summer the polar caps should disappear completely. The rate of evaporation of water vapor is, on the contrary, rather low, and it can be partially preserved. This permits one to draw the conclusion that the southern polar cap consists of fragments of ice covered by a layer of carbon dioxide. During each Martian year the carbon dioxide evap- /71 orates, exposing the ice layer (Figure 16).

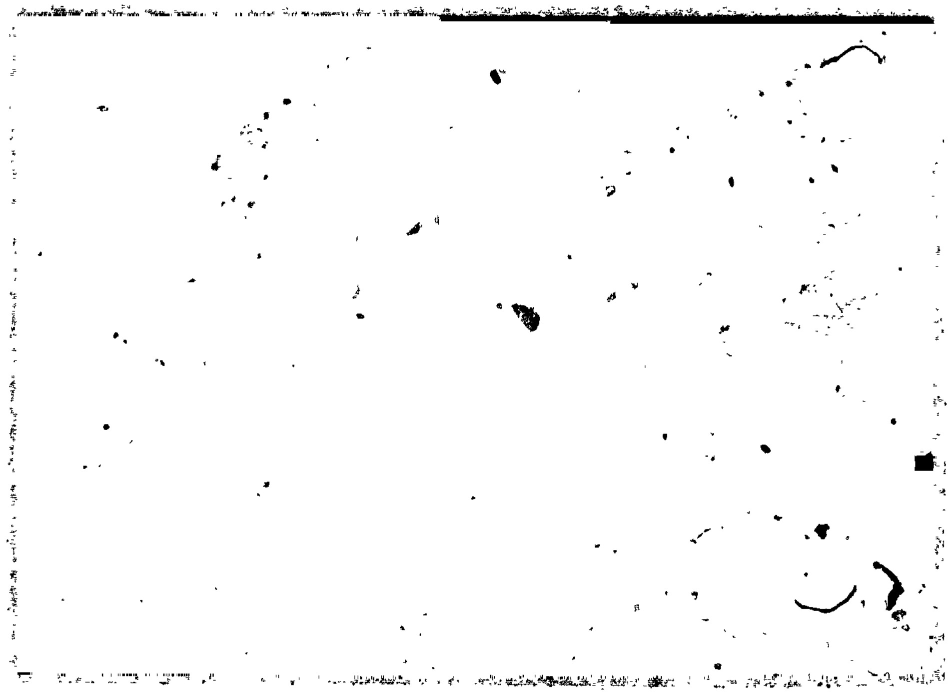

Figure 16. Region of the Southern Pole of Mars Photographed From a Distance of 3,400 km. An oval-shaped plateau is visible in the upper right-hand part. Relief elements characterized by deep gulleys and grooves having sharp edges appear in the lower part of the photograph. The depth of the gulleys reaches 500 m.

Since the times of year are closely associated with a planet's climate, let us briefly discuss this question.

The Climate of Mars

It is significantly colder on Mar than on the Earth. This is not surprising. In the first place, Mars is located one and one-half times further from the Sun than the Earth is, and solar radiation heats up its surface a little over two times more weakly than the terrestrial surface. In fact the solar radiation intensity drops off in inverse proportion to the square of the distance from the Sun! In that case the Sun shines and heats at Mars more weakly by a factor of $(1.52)^2 = 2.31$.

In the second place, as has already been stated above, the mean atmospheric pressure at the planet's surface does not exceed 6 millibars, i.e., it corresponds to the pressure in the Earth's atmosphere at an altitude of 35-40 km above the Earth's surface. And since the most severe frost becomes intense at this altitude in the terrestrial atmosphere, one can say that similar conditions exist on the surface of Mars.

There are none of the continuous cloud formations on Mars which we observe on the Earth It is almost always cloudless in any region. One can see clouds, consisting probably of ice crystals, only rarely. They are formed as the result of the condensation of water vapor floating in the atmosphere. Therefore the Martian atmosphere is very dry. It is true that there are frequent light fogs on Mars arising for a brief period mainly in the morning hours. When the air is heated up by solar radiation, they dissipate. These Martian fogs are reminiscent of the frosty haze which from time to time appears in the terrestrial atmosphere in the frosty morning time but dissipates as the air warms up.

Climatic belts occur on Mars just as on the Earth. It is true that the temperature oscillations in them are significantly greater than on the Earth. In fact there is no such abundance on Mars as on the Earth of water vapor and oceans, those powerful accumulators of heat which regulate the climate of a planet by means of storing up and releasing heat upon a change of the seasons. In view of the tenuousness of Mars' atmosphere, it cannot effectively retain the heat absorbed by its surface during the day, and because of this an enormous amount of heat escapes into outer space at night. Therefore sharp temperature oscillations are characteristic for Mars during a day. If the surface temperature at the equator in the daytime can reach +30°C, then it falls at night to -100°C and more. The mean annual temperature for the entire Martian surface is lower by 50-60°C than on Earth. For comparison we point out that on Earth it is about +10°C. The surface is heated up rather strongly at noon in the equatorial region where the Sun stands in the zenith. As the Sun approaches the horizon, the temperature rapidly decreases, and by sunset it reaches 0°. /72
At night the frost gets harder, and the temperature reaches 100°C below zero by sunrise and this all happens in the warmest equatorial belt! In the temperate belt the winter time temperature in the daytime and at night is held at a very low level — 60-80° below zero. The temperature is continuously held within the limits from zero to 10° of heat in the polar regions, where in the summer time the Sun does not quite set for several months. It is precisely at this time that the rapid disruption of the bright polar covering is observed.

Because of precession Mars' axis of rotation changes its position in space, and every 25,000 years it is oriented in such a way that neither one of the polar caps is turned in the Sun's direction at perihelion. During such periods climatic conditions can arise on Mars under which the disappearance of permafrost occurs. It is, as they suggest, accompanied by brief cloudbursts which can cause erosion processes. The channel visible on the photograph (Figure 17) is reminiscent of the traces of water erosion on the Earth.

Analyzing photographs of the Martian polar regions made by the unmanned spacecraft from a close distance, scientists are advancing suggestions about the fact that an ice age has possibly started on Mars. The southern polar cap is turned towards the Sun at the perihelion of the Martian orbit, and the cold winters are replaced here by a warm summer. The temperature contrasts of winter and summer are moderated somewhat in the north polar cap region. We note that in view of the significant eccentricity of the Martian orbit the difference in the solar constant at perihelion and aphelion of the orbit amounts to about 40%.

Paradoxical as it may seem, the polar regions of the summer hemisphere, where the non-setting Sun has time during the extended summer half-year to heat the upper soil layer up above the mean daytime temperatures over the planet's disk, are the warmest on Mars. Therefore the temperature along the meridian in the summer hemisphere varies insignificantly, and the winds are not very strong. In the winter hemisphere, on the contrary, the temperature drops sharply from the equator to the winter polar cap.

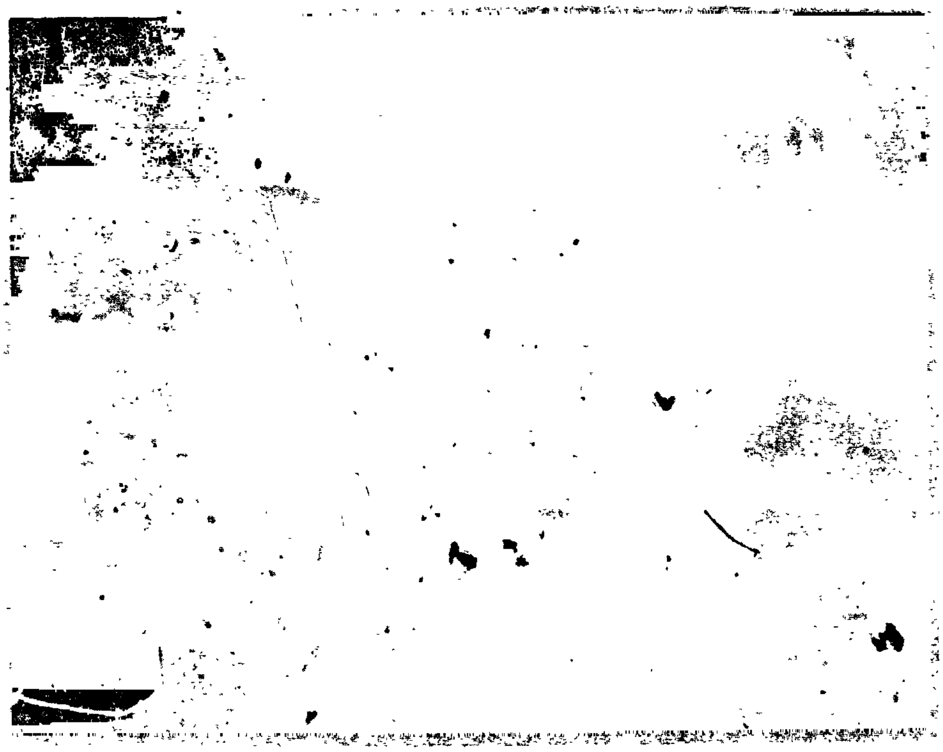

Figure 17. Section of the Martian Surface With Center at a Point Having Coordinates 29° S. and 40° W. A channel is visible which is reminiscent of traces of water erosion on the Earth.

Due to the large temperature differential in the winter hemisphere of Mars, strong winds blow. According to scientists' calculations, their velocity at an altitude of 12 km may reach 170 m/sec. Because of this, active cylconic and anticyclonic activity is developed in the atmosphere. However, our "earthly" concepts of snow or rain seldom accompany Martian cyclones. This is because there is little water in the Martian atmosphere. Therefore clouds form very rarely in the Martian atmosphere. Only in the morning and in the evening in temperate latitudes is it possible to observe clouds resembling haze. Thus if there are, of course, no dust storms, the weather on Mars always stays beautiful. Yes, and the visibility there is much better than on Earth due to the small amount of light scattering by dust particles in the air. The visibility is especially good in the summer hemisphere, where the winds are noticeably weaker and there is little dust. A strong reflection from the planet's surface of solar ultraviolet radiation has been recorded by spacecraft. The ozone layer of the terrestrial atmosphere blocks this radiation which is destructive to life. There is no such "protection" on Mars. And this has important significance for organic life.

Life on Mars

There is hardly another planet of the Solar System which has excited such hope among those who have searched for life on other celestial bodies! Starting from the 1870's, the question — "Is there life on Mars?" — wanders among the pages both of science fiction and popular literature and of scientific books. And this is explained not so much by the nearness of this planet as by its comparatively easy accessibility to inspection even with the help of not very powerful telescopes (due to the transparency of its atmosphere).

To what extent the suggestion as to the probability of intelligent life on Mars was fashionable and universal at the start even of our century is attested to by the sensation sparked by the astronomer W. Pickering of the Lowell /74
Observatory (Douglas) on December 8, 1900. In the telegram which he sent, which circled the entire World in lightning fashion, he reported that a bright outburst was visible for seventy minutes at the north edge of Mare Icaria. The question of "signal fires" of Martian inhabitants was discussed in a completely serious fashion. The presence of an atmosphere, a not-too-dry climate, and mysterious canals do not confirm whether or not any highly developed civilization exists on Mars! It is not excluded that people may encounter it in the most unexpected form on this extremely puzzling planet, which has long excited the human imagination as to the possibility of the existence of life. And some scientists remark in a completely valid manner on this question that if living organisms are found on Mars, it is possible to say without exaggeration that their study will become the problem of our century. The discovery of a new sphere of life will serve as the first biological connection of terrestrial inhabitants with a different planetary life form. And there is no doubt in that the terrestrial civilization will be able to exert a very significant effect on its subsequent development. However the complexity of the solution of this problem lies not only in sending spacecraft to Mars and deploying special instruments on its surface but determining which criteria we should judge concerning the presence or absence of life on the planet. At the present time we still do not have a sufficiently reliable method permitting us to distinguish forms "on the edge of life" from the absence of any of its characteristics but it is possible to distinguish three major groups of questions.

In the first place, there are the questions associated with whether or not the investigated planets have chemical compounds similar to amino acids and proteins;

in the second place, there are the questions associated with whether or not an exchange of materials takes place — whether or not green-type nutrient materials are absorbed by the existing life forms in chemical reactions which are characteristic of terrestrial life;

in the third place, there are the questions associated with what methods can be used to detect life forms (living), the remains of life forms (fossils), or artificial structures.

Not one of these questions is definitive, since they all allow that life on Mars is similar to terrestrial life. Nevertheless we are still obliged to proceed precisely from this assumption, taking as the basis the three distinguishing criteria of life: the exchange of materials, reproduction, and evolution. These criteria are universal for all living organisms on the Earth. From this point of view the study of the physical conditions on Mars is an exceedingly important problem with the goal of determining to what extent they are favorable to the course of biological processes. In the opinion of scientists, the data obtained do not exclude the possibility of life on Mars. The measurements carried out with the help of an ultraviolet spectrometer have shown that life forms on Mars, if they exist, must have developed a protective mechanism against this radiation.

From this point of view, great meaning is assigned to carbon dioxide, which /75 can protect from untraviolet radiation. Kuiper and Urey assume that Mars may have been warmer in the past and have had a more extensive and moist atmosphere. Its cloud cover held the temperature oscillations at a significantly lower level than at present. Oxygen appeared as the result of photolysis of water vapor in the atmosphere. Under these conditions plant life began to develop, and after photosynthesis had arisen, additional sources of oxygen appeared. However, due to the relatively low mass of the planet, oxygen can escape into outer space, The oxidation of iron at the surface could accelerate the loss of oxygen, and it is completely possible that this is just why the surface of Mars has a characteristic orange coloration. A thin, dry, and cold atmosphere was gradually formed as the result of an extended process. This process was accompanied by an increase in the intensity of ultraviolet and x-ray radiation and the flux of solar protons onto the surface. This produced dry physical conditions to which any vegetation which had arisen should have adapted.

Investigations regarding the determination of the boundaries of life have been carried out for a number of years in the space biology laboratory of the Cytology Institute of the USSR Academy of Sciences. A special camera — the "photostat" — has been created for this project. The physical conditions existing on Mars are simulated in it. The experiments have shown that some of the simplest forms of microorganisms are capable of surviving under "Martian conditions" for a rather long time, and a number of microorganisms even reproduce. Among these are microorganisms isolated from Antarctic soils. It has thus been proven that a large "reserveir of endurance" is characteristic of many living beings, which permits them to endure extremely dry conditions, including those similar to Martian conditions. This offers the possibility of suggesting the existence of microorganisms on Mars which are similar in their nature to terrestrial microorganisms.

F. Salisbury adheres to the opinion that if the appearances of life on Mars can be observed telescopically, then this life must satisfy the following five criteria:

1. It should form societies occupying large areas visible from the Earth.

2. Its coloration should correspond to what is observed and should respond to a change in temperature and humidity.

3. It should be responsible for the observed rapid variations in the sizes and shapes of dark regions and should be capable of rapidly renewing itself after dust drifts.

4. It should exhibit these properties under the dry conditions of Mars.

5. It should satisfy the fixed basic principles of ecology, such as the cycle of the elements characteristic of our planet.

On the basis of these conditions F. Salisbury assumes it to be improbable that any kind of the lowest life forms could satisfy criteria 1, 2 and 3. For /76 example, the lichens found in the Sahara and Antarctica satisfy criterion 4 better than any other known terrestrial organism. However, they cannot satisfy the remaining criteria. In fact they do not have seasonal variations of color, they grow extremely slowly, and their shape and height are such that they cannot easily work their way across a dust layer; therefore they can scarcely form colonies visible from Earth in an atmosphere of such low humidity. Thus the existence on Mars of higher vegetation is more probable, because it satisfies all these criteria with the exception of the fourth one. The presence of certain altered forms of vegetation with a pigment capable of screening it from the strong ultraviolet irradiation is also possible. This pigment may absorb solar radiation, which permits the vegetation to retain the heat. Irregardless of the extreme dryness and absence of oxygen, either a terrestrial photosynthesis cycle or some other kind of biochemical process with the participation of other elements may take place with the Martian vegetation. The founder of astro-biology, the Soviet scientist Gavrill Adrianovich Tikhov, conducted similar investigations and pointed out this possibility. He concluded that the Martian vegetation actually resembles strongly the Arctic flora of the Earth. And if about 200 kinds of plants grow in the vicinity of Verkhoyansk and Oymyakon, the coldest region of the northern hemisphere, then why could similar plants not grow on Mars?! G. A. Tikhov showed that if the predominant color of terrestrial vegetation is green, then the Martian flora should be of a sky-blue and dark-blue color. Why? Basically due to the fact that under the Martian conditions, which are dryer than on Earth, the plants will absorb more heat rays and reflect more of the cold rays — blue and violet.

The exceedingly low water content in the atmosphere and its total absence on the surface, at least, in the liquid form should be considered the most unfavorable factor restricting the possibility of the existence of life on Mars.

Reservoirs more than 300 m in diameter are completely excluded, since if any were present the planet's transparent atmosphere would cause bright high-lights of sun to be observed. However, this does not at all indicate that there is also no water beneath the surface of Mars. In fact the possibility is not excluded that a significant part of the initial water supply on Mars could have been converted into subsurface ice and thus avoid diffusion into outer space. The scientists Yu. Davydov, C. Sagan, D. Liderberg and others maintain such an opinion. In certain cases (near hot sources, regions of volcanic activity) this subsurface ice may thaw and moisten the surface, thereby creating favorable conditions for the development of life.

There is every reason to assume, asserts the Soviet planetologist V. Derpg Derpgol'ts, that subsurface Martian waters are more abundant than subterrestrial waters, since Mars is located further from the Sun, and although its atmosphere was already tenuous upon the planet's formation, there should be more water /77
maintained in it than on the Earth. Furthermore the permafrost covering of the Martian soil facilitated this. There is little free water in the atmosphere and the surface of this planet. But the associated water contained in the soils of Mars is evidently very abundant — it may form one-third of its weight. One can suggest rather confidently that the soils covering the surface of Mars are similar to a hydrate of iron oxide, the so-called limonite, whose composition consists of approximately 34% water. One can get this water out of the soil if it is greatly heated.

In order to reply to the question of whether or not life has arisen on Mars, it is necessary to investigate the Martian conditions and clarify what paths the planet has followed. If, let us say, it were established that oceans existed on Mars at some time or other, this would mean that the possibility of life having arisen there would become very probable. It is well-known that the presence of nitrogen is necessary for the formation of complex organic compounds. There is less than 5% of it in the Martian atmosphere. But if there is now practically no nitrogen, was this the case earlier?

The situation is exactly the same with oxygen. Up until the present it has not been detected on Mars at all. But anaerobic microorganisms live on the Earth, which manage without it; moreover there are even microbes which perish from this "life-giving" gas.

One of the most unfavorable circumstances is the fact that the sparse atmosphere of Mars does not vigorously block the powerful ultraviolet radiation of the Sun, which reaches the planet's surface there. And it is well-known that the action of such irradiation is destructive to terrestrial life forms. And if there were no ozone layer in the terrestrial atmosphere, which absorbs a large part of the solar ultraviolet radiation, it is completely probable that there would be no life similar to terrestrial life on our planet.

It is true that one should not forget about the capability of living organisms to adapt themselves to foreign conditions. In fact there is practically not a single sterile place on our planet: in the ices of Antarctica and in the scorching heat of the Sahara, in the depths of the Pacific Ocean and on the gigantic peaks of mountains — everywhere we find the simplest living organisms. They even live in nuclear reactors!

The photographs of Mars made from onboard the unmanned spacecraft have not given direct proofs of the existence of life on Mars. The abundance of craters and the absence of tectonic structures similar to those on Earth indicate that there have been no oceans comparable in size with terrestrial ones within the very recent past on Mars, and it is most likely that there never were any. All the same, disregarding this, many scientists prefer not to rush into final conclusions on this question. Because of the presence on Mars of relief forms whose origin can be explained only by the action of liquid erosion, the indications of the presence of ice in the southern polar region, and the escape of water vapor from the atmosphere — all of these permit us to suggest the possibility of life on Mars.

Oppositions of Mars /78

Moving along its orbit, the Earth, having a greater velocity than Mars, covers its shorter path more rapidly, and therefore from time to time it overtakes Mars and then passes it. When this occurs, the Sun, Earth, and Mars lie along a single straight-line. Such an arrangement of these objects is called an opposition, because at this time a terrestrial observer sees Mars at a point in the sky exactly opposite to the Sun (Figure 18).

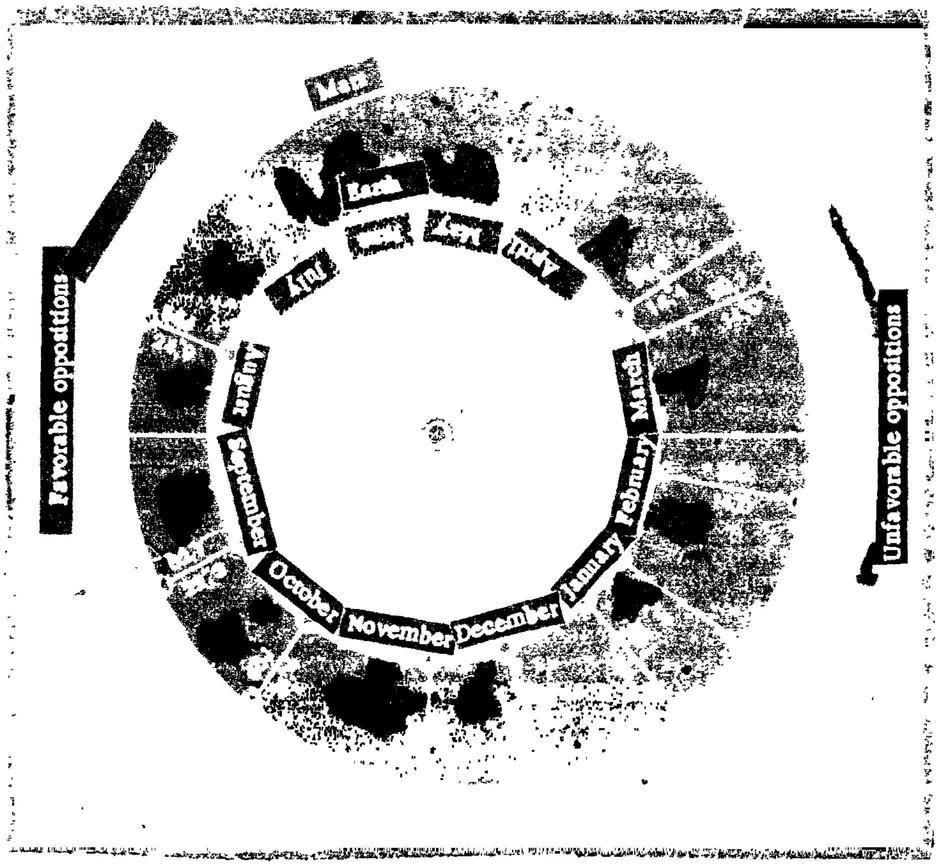

Figure 18. Arrangement of the Earth and Mars in Their Orbits at the Time of Oppositions: A, Aphelia; P, Perihelia. The distances are given in millions of kilometers, and the angular diameter of Mars as observed from Earth is given in seconds of arc.

Oppositions of Mars with respect to the Earth occur on the average every 780 days (the mean synodic period of revolution of both planets). If the orbits of these planets were concentric circles lying in the same plane, and if they /79 had a common center at the center of the Sun, all oppositions of Mars would be completely identical, and the distances between the planets would always be the same. But the eccentricity of the planetary orbits and the fact that they lie in different planes disturbs this imaginary orderly picture. Therefore one opposition differs from another. It turns out that Mars is almost 100,000,000 km away from the Earth at the time of an opposition, and the Earth-Mars distance is shortened to 56,000,000 km at the most favorable of these. Such oppositions are called great ones. Since the actual synodic period differs from the mean synodic period by 20 days, the great oppositions are repeated every 15-17 years, although both planets regularly encounter each other every 780 days in various parts of their orbits. Since at the time of great oppositions Mars approaches nearest of all to the Earth and is located at a distance of approximately 56,000,000 km, the most favorable opportunity for astrophysical observations of Mars occurs at this time. The last such opposition took place on August 10, 1971. But the approach of the two planets to the minimum distance (due to the eccentricity of their orbits) does not occur on the day of the great opposition, but two days later. On August 12 the Earth-Mars distance was a minimum — 56.2 million km. At this time the diameter of Mars visible from the Earth increased to 25 seconds of arc, and its brightness reached 2.6 stellar magnitudes (we point out for comparison that the brightest star Sirius has a brightness of 1.4 stellar magnitudes). Although the opposition itself, strictly speaking, occurs only at some single specific instant of time or other, it is convenient to observe Mars prior to and after the opposition (for approximately 2-3 months).

The advantages of great oppositions consist not only of the fact that Mars approaches close to the Earth, but that they occur in August and September when the conditions for observing Mars are the most favorable. It is still no less important that at this period Mars remains comparatively close to the Earth for several months. Therefore it is not surprising that precisely the years of great oppositions were always the most fruitful with respect to new discoveries concerning Mars. It is precisely at these periods or in the years closest to them that the "maria" and "continents" (in 1836 by the Italian astronomer Fontana), the polar cap (in 1716 by the astronomer Moraldi), and the famous canals and cases (in 1877 by the Italian astronomers Secchi and Schiaparelli) were discovered on Mars. In that same year (1877) the American scientist Hall discovered the two satellites of Mars. The seasonal variations in color on the planet's surface (1892) and the dust storms (1909) were recorded during periods of great oppositions. As the result of observations of Mars during the period of the great opposition of 1956, success was achieved ir ecording significant variations in its atmosphere and on the surface of powerful dust storms and fogs. The atmosphere of Mars was very opaque and filled with haze. Regardless of this, scientists noticed a variation in the intensity of dark and light features on /80 the planet's surface. During a great opposition Mars is situated in such a way that its southern hemisphere is turned towards the Sun and the Earth. At this time it is always fall in the northern hemisphere of Mars and spring in the southern. Therefore a large part of the information acquired about Mars was obtained from investigations of its southern hemisphere.

Phobos and Deimos

The satellites of Mars have a rather curious history. The Irish satirist Jonathan Swift first mentioned them in the pages of his fantastic satirical novel "Gulliver's Travels" as early as 1726. Here is what he wrote:

"...This advantage hath enabled them to extend their discoveries much farther than all astronomers in Europe. They have made a catalog of ten thousand fixed stars, whereas the largest of ours (referring to the European — N. V.) do not contain above one-third part of that number.[9] They have likewise discovered two lesser stars, or satellites, which revolve about Mars, whereof the innermost is distant from the center of the primary planet exactly three of his diameters, and the outermost five; the former revolves in the space of ten hours, and the latter in twenty-one and a half; so that the squares of their periodical time are very near in the same proportion with the cubes of their distance from the center of Mars, which evidently shows them to be governed by the same law of gravitation that influences the other heavenly bodies..."

This was written by J. Swift at the same period when I. Newton discovered the law of universal gravitation, which controls the motion of celestial bodies, and his theory of gravitation agitated all thinking people. Several years after J. Swift the great Voltaire wrote about the two satellites of Mars in his "Micromegas" (1752): "A man more than 30 km in height who arrived from one of the planets of Sirius together with an inhabitant of Saturn, a real "dwarf" no more than 1 1/2 km in height, decided to investigate the Solar System. Their stay on Mars was very brief, since it turned out to be too small for them. But, similar to Gulliver, they discovered that Mars has two satellites."

The actual discovery of the satellites of Mars belongs to the American astronomer Asaph Hall. Observing Mars in a year of a great opposition (August 11, 1877), A. Hall discovered a faintly luminesce small star near the planet's bright disk. The following nights were cloudy, but on August 16 the visibility was again good, and he saw a second such small star not far from the small star observed earlier. Both of these moved around Mars in the plane of its equator. According to tradition A. Hall gave them the names of the two sons of the Roman God of War, Ares (Mars), who accompanied him in battles at the time of the Trojan /81
War — Phobos and Deimos (Fear and Terror). Phobos, the nearest to Mars, moves along an almost circular orbit at a distance of about 9,380 kilometers from the planet's surface. It completes a revolution around the planet in 7 hours 39 minutes 13 seconds, i.e., a little more than three times faster than the axial rotation period of the planet itself. If one takes into account the fact that the days on Mars last 24 hours 37 minutes, then Phobos has time to race around the planet almost three times while the planet itself is making only one rotation. Incidently, this is a unique case, known in astronomy, in which a natural satellite revolves more rapidly than the planet itself rotates. In an hour Phobos has moved by 33°. Since the direction of motion of the satellite and the planet are one and the same, an observer located on Mars will see it

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[9]The "British Catalog of Fixed Stars," published in 1725, included less than 3,000.

rapidly moving counter to the entire stellar round dance and setting not in the west, as all stars do, but in the east.

Deimos is 23,500 kilometers distant from the planet's center. It completes an entire revolution around Mars in 30 hours 17 minutes 17 seconds. Located on Mars, it is possible to observe its slow displacement among the stars from east to west by 3° each hour. Therefore it is located above the horizon about 65 hours from rising to setting.

For imaginative inhabitants of these two satellites, the planet Mars itself should appear incomparable with anything, a majestic and truly splendid picture. From Phobos the surface of Mars would appear to be 6.7 thousand times larger than the Sun as seen from the Earth. And its gigantic body would be observed three times a day in the firmament of Phobos passing through all the phases exhibited by our Moon each month.

Perhaps these satellites would not be of especially great interest if they did not possess certain specific peculiarities.

In the first place, no other single planet has such small moons (the size of Phobos is 25 by 21 km, and that of Deimos is 13.5 by 12 km with a measurement error of from 0.5 to 5 km). In the second place, they are very close to their planet. In the third place, Phobos and Deimos move along orbits whose planes are only insignificantly inclined to the plane of Mars' equator (1.8° and 1.4°, respectively). And finally, the American scientist B. Sharpless suspected in 1940 that Phobos was moving in an accelerated manner and very slowly approaching Mars along a spiral. The period of its revolution is decreasing by approximately one-millionth of a second. Many different suggestions were advanced regarding this question. In 1959 the Soviet scientist I. Shklovskiy, having analyzed all the hypotheses suggested, came to the conclusion that the single acceptable explanation of the very strange behavior of Phobos may be its hollowness. Thus arose the daring hypothesis as to the artificial origin of the satellites of Mars. According to his suggestion, they were created many millions of years ago by rational beings. There were probably conditions favorable to life on Mars at that distant time, and rational inhabitants existed there who had attained a very high level of culture. And it is possible that they are the abandoned monuments of some highly developed civilization which /82
existed at some time or other. This hypothesis, which is rather close to science fiction, created quite a furor in its time.

A scientific co-worker of the Shternberg Astronomical Institute, S. Vashkov'yak, rather recently worked out a new analytic theory of the motion of Mars' satellites which takes into account the non-sphericity of the planet, the gravitational influence of the Sun, and the mutual perturbations of Phobos and Deimos. Having applied this theory to the observations of the Martian satellite motions over 50 years (from 1877 to 1926), S. Vashkov'yak showed that the calcu- /83
lations of B. Sharpless were in error. There is actually not any acceleration of Phobos. Since the satellites are very small, solar eclipses never occur on Mars.

Mariner-7 photographed Phobos against the background of the Martian surface. A careful analysis of this photograph showed that Phobos is shaped like a melon, and what is most curious, its surface is very dark. It reflects about 6% in all of the solar light, and therefore it is the darkest object in the Solar System.

The possibility is not excluded that Phobos and Deimos are former asteroids which were captured at some time by Mars and consigned by it to their contemporary orbits.

The Sky of Mars /84

Even prior to the flight of the cosmonauts, pilots reported that as their altitude increased, the sky became darker and darker. Its light-blue color gradually changes into blue, and then into dark-blue. This occurs because of the fact that the higher one goes, the lower is the air density. And in that case, the pale-blue and blue rays of the solar radiation are scattered less there. We learned from a lecture of the World's first cosmonaut Yuriy Gagarin that the sky seemed coal-black from the Vostok spaceship. This was confirmed by other cosmonauts.

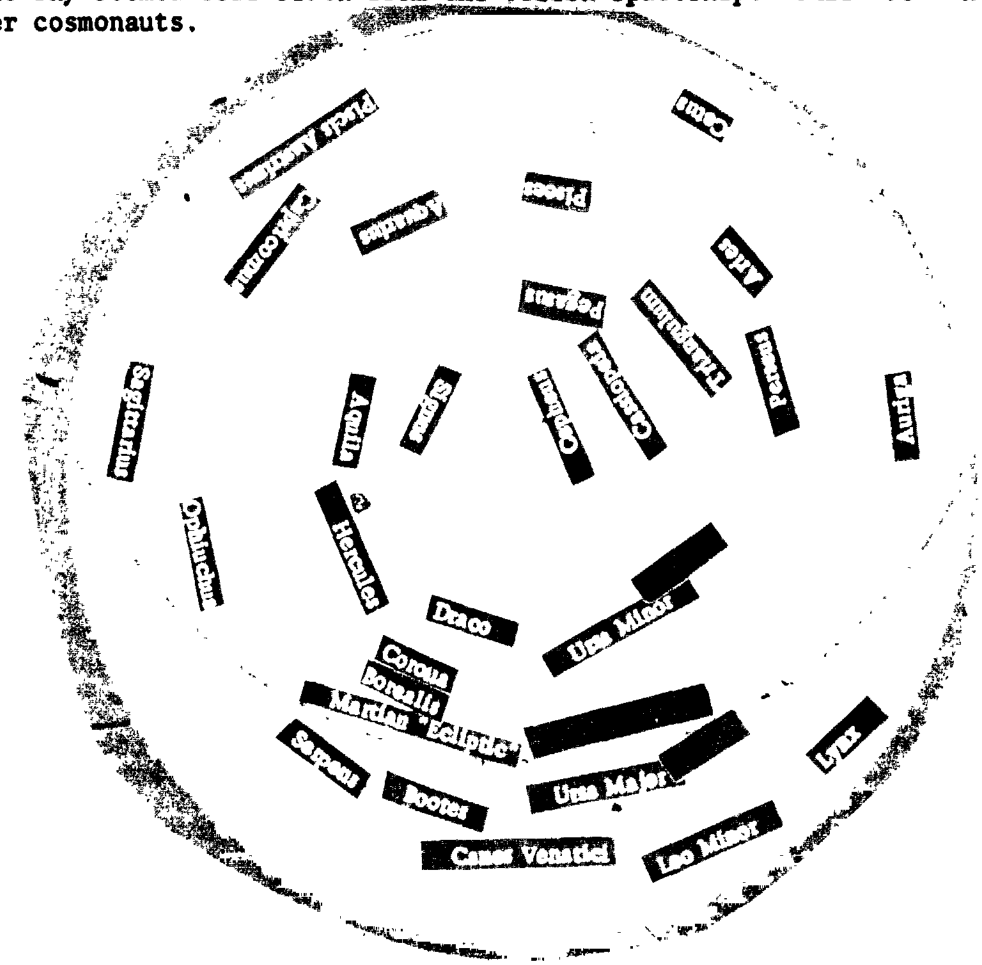

Figure 19. Map of the Celestial Sky of Mars. Northern Hemisphere.

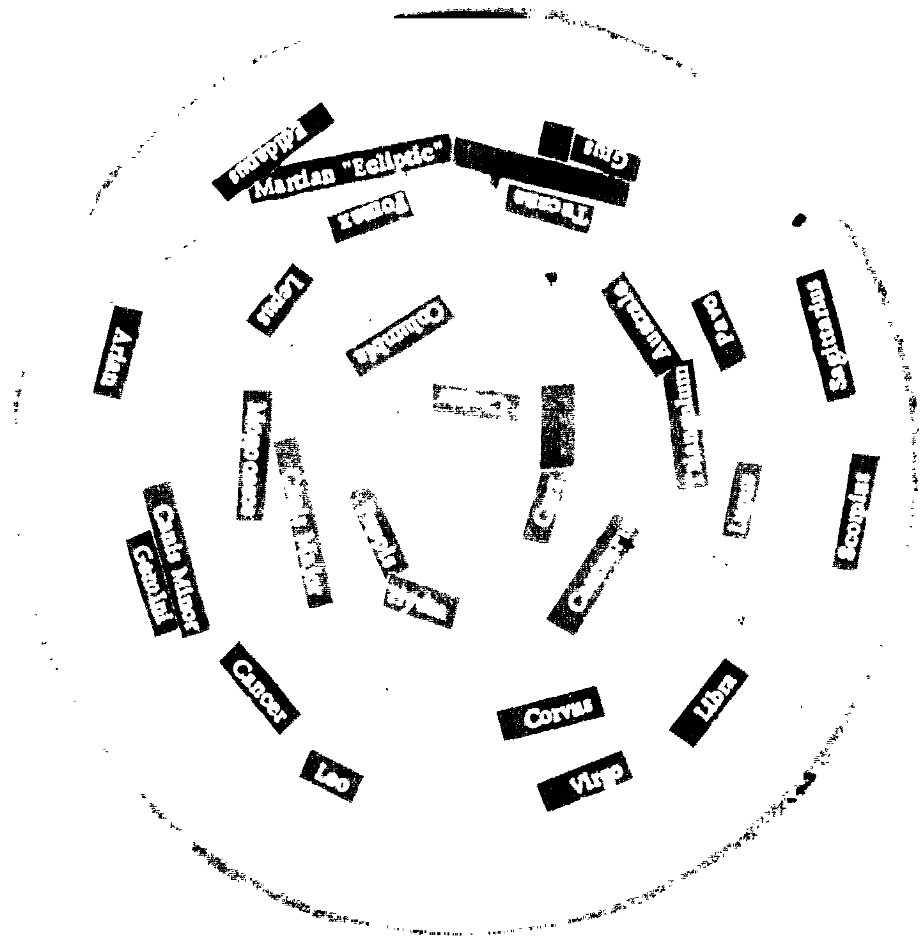

Figure 19. Map of the Celestial Sky of Mars. Southern Hemisphere.

As we have already said, the density of the gaseous envelope at Mars' surface is approximately the same as at an altitude of 30-35 km above the Earth's surface. Therefore the color of the Martian sky in the daytime has a dark-blue coloration. In fact the nature of light scattering by a gaseous medium does not depend on its chemical composition but is determined by the sizes of the particles scattering the sunlight. In pure dust-free air gas molecules scatter the light. Their dimensions are evidently just as small in the Martian atmosphere as in the terrestrial atmosphere. On Earth the light scattered in the atmosphere colors the firmament in pale-blue tones. This occurs because small particles scatter precisely the pale-blue rays inside the gaseous envelope.

Since the inclination of Mars' orbit to the ecliptic is insignificant (only 1°51' in all), the Sun's path among the stars passes through the same zodiacal constellations for an observer located on Mars as for a terrestrial observer (Figure 19). Our diurnal star appears less bright, and the diameter of its visible disk is one and one-half times smaller than when observed from the Earth. The diurnal rotation of the celestial sphere occurs at almost the same speed as in the terrestrial firmament. But since the orientation of Mars' axis of rotation is different from the position of the Earth's axis in space, the rotation of the celestial sphere occurs around a different point. The northern celestial pole is situated in the constellation Signus and is not noticeable against the background of the Milky Way by any kind of bright star. One can find the location of the pole among the stars at the middle of a line connecting the stars Alpha Sephei and Alpha Cygni (Deneb). The southern pole is located in the constellation Vela. The outlines of the constellations in the Martian sky are similar to the terrestrial ones.

Due to a significantly lower atmospheric density than on Earth, the stars will look brighter, and their twinkling will be less noticeable. The bright stars located on the celestial sphere near the zenith can be seen even in the daytime, of course, in the absence of cloudiness and dustiness of the atmosphere. The planets in the Martian sky will be visible, just as on the Earth, within the limits of the zodiacal constellations. Since the Earth's orbit lies within the orbit of Mars, it is impossible to see the Earth in the full phase from Mars. The same thing applies to Mercury and Venus. The maximum distance of the Earth from the Sun does not exceed 30-35°. The belt of the Milky Way passes through both celestial poles in the Martian sky. Located at one of Mars' poles, an observer will be able to see during the polar night how the enormous arc of the /85
Milky Way, which passes through the zenith, rotates about him every day. And he will be able to see at Mars' equator how during the sky's diurnal rotation the arc of the Milky Way rises in the eastern direction of the Martian horizon, passes through the zenith, and disappears below the horizon in the west, as if it were attached at the north and south points. Simultaneously another arc appears in the east — the other half of the Milky Way ring.

The belt of the Milky Way appears to be the best reference for an approximate determination of the directions of the horizon on Mars. The points at which the middle of the belt intersect the horizon line are the north and south points.

In conclusion of this chapter it is necessary to say that Mars has an enviable destiny — there are no people indifferent to it. The history of its knowledge indicates that just as soon as some new hypothesis or other appears, it immediately captures ardent adherence and no less tempermental opponents. But whether the hypotheses are valid or not, the well-known Canadian physiologist S. Selway noted, they have always determined the directions of scientific searches.

CHAPTER 4.
VENUS: WHAT DO WE KNOW ABOUT HER!

There is no other planet in the Solar System whose investigation for the last several years has altered the concept of it so strikingly and rapidly. Even quite recently Venus was imagined by people to be the most enigmatic planet. And there were very serious reasons for this. Being blanketed by a thick and opaque to optical means (telescopes) shroud of clouds, it jealously concealed from people the secrets of all that was taking place on its surface. Located nearer to the Sun than the Earth, it is visible in the Sun's direction when it is nearest to the Earth. It literally "drowns" in its bright rays, and it even has its hemisphere which is unilluminated by the Sun turned towards us at that time. /86

More than 350 years passed from the time when Galileo directed the first telescope in the World at Venus and saw that it was not a star at all but a spherical object similar to the Earth, illuminated and heated by the Sun. He discovered its phases — evidence of the planet's revolution around the Sun. The next unusually important landmark in the study of Venus was the discovery on it of an atmosphere by the Russian scientist M. V. Lomonosov. This occurred on May 26, 1761. Observing a transit of Venus in front of the Sun, when it was at inferior conjunction, he noticed the appearance of a white luminescent border — a glow thin as a hair — around the portion of the planet which had still not passed completely onto the Sun's disk. When Venus approached the other edge of the solar disk, then a luminescent ring was also observed, but now on the other side, around the dark disk of Venus. M. V. Lomonosov correctly explained this phenomenon as the result of the refraction of solar rays in the dense atmosphere of Venus. I recall the lines from his lecture to the Russian Academy of Sciences which have now become a classic: "The planet Venus is surrounded by a notable air atmosphere, the same (only not as extensive) as surrounds our terrestrial /87 sphere..."

Subsequent observations confirmed this brilliant conclusion, and the discovered phenomenon received its own name of the "Lomonosov phenomenon".

After 350 years of telescopic observations scientists have gradually become attached to the idea that Venus is very similar to the Earth. This conviction was substantiated by theoretical calculations and observational results.

Thus if the diameter, density, and mass of the Earth and the acceleration due to gravity are taken as unity, these same physical quantities for Venus will be equal to 0.97, 0.88, 0.81, and 0.90, respectively. Therefore one might expect that the development of its interior and surface occurred almost in the same way as the Earth's development. Since both planets condensed in the same region of the protoplanetary cloud and their average density is approximately the same, then evidently the average chemical composition of their interiors should be similar. Yes, and their atmospheric compositions are probably identical. And in that case life similar to that on Earth may have developed under physical conditions on Venus similar to those on Earth. A regular and logical comparison led the investigators to such conclusions.

In the 1930's it was established with the help of spectral analysis that Venus' dense atmosphere consists primarily of carbon dioxide gas. There are reasons to assume that the Earth's atmosphere initially consisted of carbon dioxide gas. And if a large amount of oxygen and nitrogen is now contained in it, this is associated with subsequent changes in the atmosphere's composition due to the effect of the vital activity of vegetable and animal life.

Study of photographs of Venus has permitted the Soviet astronomer N. P. Barabashov to establish that Venus reflects sunlight the same way as does a surface possessing certain mirror properties. Proceeding from this fact, he concluded that Venus is probably covered by a continuous layer of water — an ocean. The large carbon dioxide gas content in its atmosphere can be explained by the fact that it is isolated from the solid surface. If this were not so, all the carbon dioxide gas would enter into chemical reactions with the rocks and would be used to convert them from silicates to carbonates. The discovery of carbon dioxide gas on Venus resulted in one more attractive hypothesis. Conditions prevail on Venus which are similar to those on the Earth over 200,000,000 years ago in the Carboniferous Period, when tree-ferns grew everywhere, the climate was very warm and humid, and the sky was continually filled with clouds.

In 1956 it was established that Venus emits radio waves. Radio astronomers immediately used this discovery. In fact the radio waves have a very important advantage over light rays (and also over ultraviolet and infrared rays): they pass freely through the cloud layer and dense atmosphere of the planet, and therefore they can tell us much about the properties of its surface and the /88
conditions which prevail on it. In radio astronomy the intensity of the radio emission of the planets is expressed in units of the so-called "radio brightness temperature"[10]. For thermal radiation it is close to the true temperature of the radiating object. The duration of the investigation of Venus' radio emission in the centimeter wave region, which pass through the Earth's atmosphere almost unhindered and, as was expected, through Venus' atmosphere, led to notions that the surface of Venus may be very hot with a temperature of 350-400°C.

Radio astronomers struck a very appreciable blow against the attractive and promising hypothesis as to the dawn of life on Venus with this literally sensational discovery. It turned out that Venus emits radio waves like a black body heated up to 400°C. It is completely clear that at such a temperature life (in our terrestrial understanding) is unthinkable. Yes, and it is unnecessary to speak about the presence of a continuous ocean on Venus. Therefore there can be no more talk about any similarity of conditions on Earth and Venus. But since these new data have contradicted the traditional views and established hypotheses, many scientists could not believe that the source of this radio emission

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[10]The radio brightness temperature is the temperature of an absolute black body with equivalent emission in the radio region.

was the burning hot surface of Venus. Therefore other, no less interesting hypotheses then arose which attempted to reconcile these new results with notions about a comparatively temperate climate on Venus. The planet's high surface temperature, asserts the American scientist C. Sagan, is explained by the fact that more than 40% of the sunlight reaches the planet's surface and thereby heats it up greatly. A heated-up surface emits, as is well-known, heat in the form of infrared radiation which is strongly absorbed by the carbon dioxide gas and water vapor of Venus' atmosphere and thereby warms it up, similar to the way in which glass holds in the heat in greenhouses and warms them up. Thus Venus' entire atmosphere acts like a gigantic greenhouse, holding in the solar heat. An analogous greenhouse effect is observed on the Earth. It is produced by the fact that the terrestrial atmosphere is significantly more transparent to solar radiation than to the thermal emission coming from the Earth's surface. However, a large amount of water or a high pressure at the planet's surface are necessary to achieve the greenhouse effect. Therefore, points out the astronomer D. Johnson, the enhanced radio emission in the centimeter range is attributed not to Venus' surface but to its hot ionosphere. Similarly to the Earth's atmosphere, there may be a layer in Venus' atmosphere with an enhanced concentration of charged particles (ions and electrons), the so-called ionospheric layer, which is the source of the emission of the centimeter radio waves. They indicate a strongly heated ionosphere of Venus.

No, centimeter waves give the correct idea as to the surface's high temperature, asserted the Irish astronomer E. Opik, but the cause of its being heated up so greatly is not the greenhouse effect, produced by the atmosphere, but very powerful winds transporting clouds of mineral dust. The kinetic energy of the winds is again converted into heat due to the friction between the dust particles. /89

The Soviet scientists A. Lebedinskiy and V. Vakhnin suggest that the source of Venus' radio emission may be completely due to decaying discharges occurring in its atmosphere. It is known that the so-called decaying electrical discharges in rarefied gases produce very intense radio noise emission with little thermal heating of the medium surrounding the discharge. Let us recall that the usual gaslight tubes used in luminescent advertisements produce radio noise emission equivalent to a temperature of 10,000-40,000° Celsius, but intense infrared radiation is absent, and the walls of the tubes remain cold. The noise emission originating from a decaying discharge is constant in intensity with time and has a continuous spectrum of frequencies, which makes it practically indistinguishable from the radio noises of a heated object. One can suggest that continuously or almost continuously similar decaying electrical discharges, creating an enhanced intensity of radio noises, occurs in the upper layers of Venus' atmosphere.

And so one logically arrives at the following interpretation: Venus' surface has a comparatively low temperature of the order of +50-60°C, and decaying discharges, which give an increment to the equivalent radio noise temperature of the order of 200-250°C, are "responsible" for the remaining part of the radio brightness.

This brings to our attention the fact that the "daytime" and "nighttime" sides of the planet are identically "hot". In connection with this, the obvious suggestion arises as to a high internal temperature. Using the methods of radar probing of Venus, it has been possible to establish the rate and direction of rotation of Venus, refine the distance to it, and determine the radius corresponding to the level of the cloud layer. It turned out to be equal to 6,050 ± ± 5 km. The variation of elevations on the planet's surface evidently does not exceed 5 km. It turned out that a large portion of the planet's northern hemisphere is mountainous, and the southern hemisphere is comparatively smooth.

The perfecting of spectral methods in the infrared radio wave region came simultaneously with the attack on Venus' secrets by radio astronomical and radar methods. They gave the first estimates of the chemical composition and temperature in the sub-cloud layer of the atmosphere of Venus. The results of the spectral measurements indicated the presence of carbon dioxide gas and also of minor impurities: oxygen, water vapor, hydrogen chloride, and hydrogen fluoride. However, they did not permit obtaining a unique answer for the cause of the high radio brightness temperature of Venus. A still larger indeterminacy was in the estimates of the value of its surface pressure: to what pressure can the corresponding very high temperatures correspond? This question remained /90
unanswered. With the atmosphere's chemical composition not known, values from one to several hundred atmospheres were quoted even on the assumption that the surface of Venus is hot. It was also not known what was the nature of the temperature variation near the clouds and what the depth of the atmosphere was.

Individual contrast features not distinguishable in the visible part of the spectrum were detected in the structure of Venus' clouds when observing from the Earth in the ultraviolet. It was discovered that the shifting of these features, which received the designation of "ultraviolet clouds", along the planet's disk occurs far more rapidly than the intrinsic rotation of the planet itself — approximately 60 times faster. A leading rotation of the Earth's atmosphere no more than by a factor of 1.2-1.4 has been found only at significantly high altitudes of 150-400 kilometers. The nature of this interesting phenomenon is still not completely clear. On Venus it is most likely associated with peculiarities in the heat exchange and planetary circulation at the level of the cloud layer.

A very sharp qualitative discontinuity occurred recently in our knowledge of Venus' atmosphere when the automatic interplanetary stations not only probed its atmosphere but landed on its surface.

First Scouts of Venus

Soviet scientists, engineers and workers, the creators of the Venera series of unmanned spacecraft, made an enormous contribution to the substance of the investigation of Venus. The first such spacecraft, Venera-1, was launched from the Soviet cosmodrome at Baykonur on February 12, 1961 (Figure 20). After 97 days of flight, it flew by at a distance of 100,000 km from Venus and went into orbit as a satellite of the Sun. Among the problems it studied were cosmic rays, magnetic fields, the interplanetary gas, meteoric particles, and solar /91 radiation. It was also necessary to explore the possibilities of extremely long-distance radio communication and flight control in near-solar space. The radio link with the spacecraft was maintained out to a distance of 23 million kilometers. At this time this was a record for deep space communication! Having blazed the first interplanetary path in the history of terrestrial civilization with a length of 270 million kilometers, the spacecraft went into a heliocentric orbit and became an artificial satellite of the Sun.

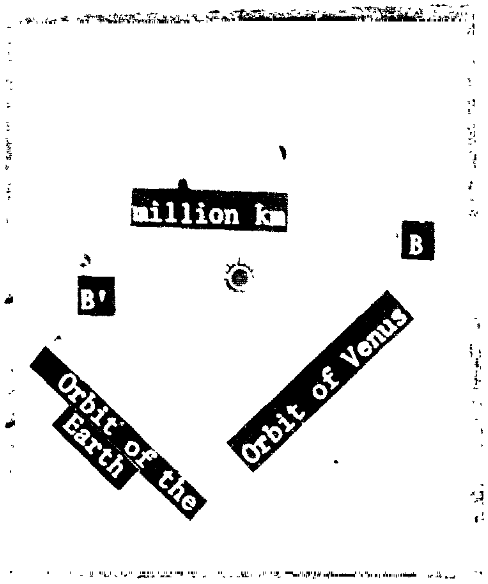

Figure 20. Schematic Diagram of the Motion of the Venera-1 Unmanned Spacecraft Relative to the Sun (Projection onto the Plane of the Earth's Orbit): A, Position of the Earth at launch; A', Position of the Earth upon the spacecraft's rendezvous with Venus; B, Position of Venus at launch; B', Position of Venus at rendezvous with the spacecraft; γ, Direction to the vernal equinox.

Approximately a year later, on August 27, 1962, the American Mariner-2 spacecraft was launched to Venus. Having covered in 109 days a path of 240 million kilometers, it approached Venus to within 35,600 kilometers. Then the spacecraft went into a heliocentric orbit and also became an artificial planet of our Sun. The instruments mounted on it communicated that Venus does not have a magnetic field and radiation belts.

As the result of these investigations, scientists found out that the temperature of the planet's surface is very hot, the atmospheric pressure is tens of times greater than that on Earth, and the density of its atmosphere is higher by far.

On November 12 and 16, 1965 two Soviet unmanned spacecraft — Venera-2 and Venera-3 — were launched to the mysterious planet. Both of them had an orbital and a special hermetic compartment. The descent stage of the Venera-3 spacecraft consisted of a sphere 900 millimeters in diameter within which scientific instruments were mounted.

On February 27, 1966 Venera-2, having completed the flight along its heliocentric orbit in 108 days, flew by at a distance of 24 thousand kilometers from the surface of the investigated planet, and Venera-3, after a 106-day flight, first entered its atmosphere and on March 1, 1966 delivered to Venus' surface a pennant with an image of the USSR coat of arms on one side and a diagram of part of the Solar System on the other side. The position of the Earth and Venus in their orbits corresponded to the time for the flight of a spacecraft to the neighboring planet. For the first time in the history of cosmonautics, two spacecraft flew along almost the same identical path. On account of this scientists were given the opportunity to compare readings of their scientific instruments. Investigations carried out by these spacecraft permitted refining a number of important characteristics associated with the dynamics of interplanetary spaceflight and obtaining scientific data about outer space in the year of the quiet Sun.

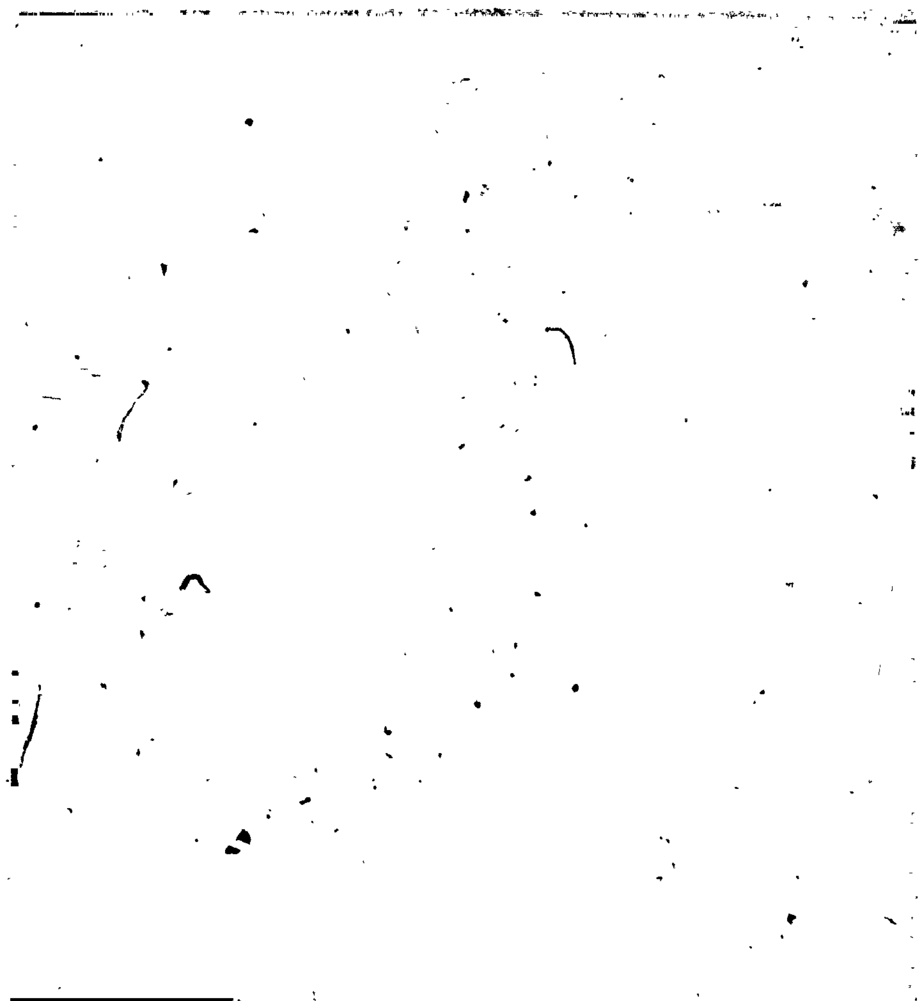

Figure 21. The Venera-4 Unmanned Spacecraft in the Assembly Shop.

The flight of the unmanned Venera-4 spacecraft (Figure 21) was the greatest success in the study of Venus and a new prominent contribution to the development of our native cosmonautics. Launched on June 12, 1967, it covered a path of 350 million kilometers in 128 days, and on October 18 it entered the upper layers of Venus' atmosphere (Figure 22). A descent stage weighing 383 kilograms, which as a fire-proof sphere surveyed the sky of Venus, separated from it and, having been braked in the planet's atmosphere, completed an almost one and one-half hour smooth descent by parachute. First direct measurements were carried out of the chemical composition, temperature, pressure and density of Venus' /92
atmosphere. It was established that the temperature upon descent along a stretch with an altitude differential of the order of 28 kilometers increased from +25

to +270 degrees Celsius, and the atmospheric pressure varied in the same interval from 1 to 18.5 atmospheres. With the help of a magnetometer and four charged particle traps, a sharp increase of the magnetic field and the fluxes of positive ions was recorded for the first time. This evidently occurred as the result of the spacecraft's passage through a shock wave front which arises upon the solar /93
plasma's flowing around the planet's body.

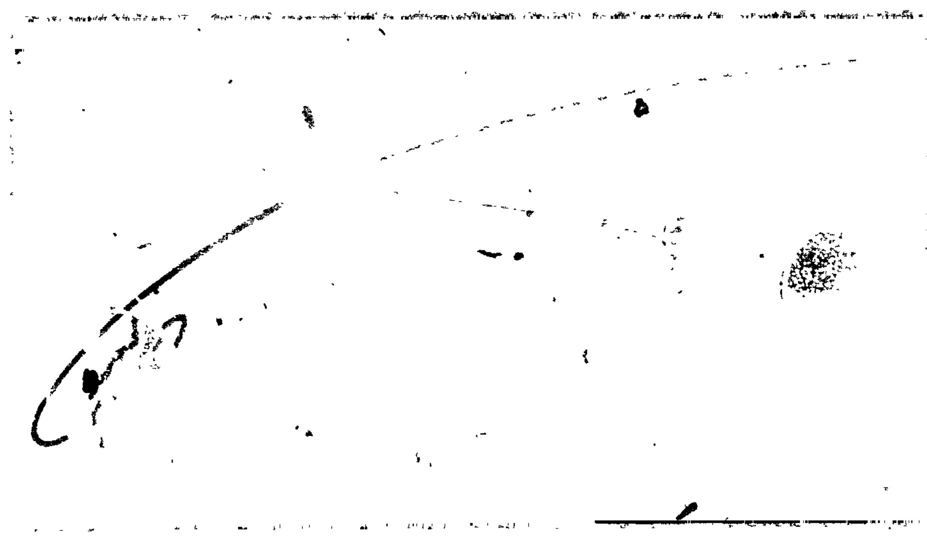

Figure 22. Main Phases in the Flight of the Venera-4 Spacecraft: 1, Placement into an intermediate orbit as an artificial Earth satellite; 2, Transition to the flight trajectory to Venus; 3, Correction; 4, Planetary approach phase; radio link with the Earth via the parabolic antenna; 5, Braking of the descent stage in Venus' atmosphere; 6, Descent by parachute; Conducting of scientific measurements and transmissions of information to the Earth.

The most important result was the analysis of the samples of gaseous composition, which put an end to arguments about what gas predominates in the atmosphere of Venus. It turned out that the atmosphere consists almost entirely of carbon dioxide and not of nitrogen, and water and oxygen are minor impurities.

Days after this unique experiment the American Mariner-5 spacecraft flew near Venus. From a distance of about 4,000 kilometers, it "illuminated: with its radio beam right through the atmosphere of Venus along a tangent to the planet's surface. This radio beam was received on Earth. Having compared the observed change in frequency with what it would have been in the absence of the atmosphere due to the Doppler effect, scientists studied the variation of the index of refraction in the altitude range 70-35 kilometers. After a careful reduction of the data obtained by the sounding of Venus' atmosphere by the Venera-4 spacecraft, and also taking into account the results of the recent radio astronomical and radar measurements obtained by the Mariner-5 spacecraft, scientists advanced the suggestion that the values of the pressure and temperature at the planet's surface should be higher. But what are they? In order to get an answer to this question, Soviet scientists carried out a new more complex experiment, namely: the sounding of Venus' atmosphere simultaneously by two spacecraft of the same kind at two different but adjacent regions of the planet. For this purpose the Venera-5 and Venera-6 unmanned spacecraft were launched on January 5 and 10, 1969. Having safely survived all the dangers of the many-months space journey, both spacecraft reached the designated planet on May 16 and 17 of the same year, and they completed a smooth descent in its atmosphere and delivered to its surface a pennant with a bas-relief of Vladimir Il'ich Lenin and an image of the coat of arms of the USSR. /94

Both spacecraft resembled their predecessor with respect to their design, but some systems and instruments were improved or replaced, taking account of the results obtained earlier. Thus, for example, the investigators proceeded in their preparation of the Venera-4 unmanned spacecraft on the basis that nitrogen is the main component of Venus' atmosphere and that there is more of it than there is carbon dioxide gas. Therefore the nitrogen detector (the instrument for measuring nitrogen) was designed for large amounts of nitrogen, but it turned out that there is less than 7% of it in Venus' atmosphere, while carbon dioxide gas accounts for more than 90%. Prior to the flight of Venera-4 astronomers assumed that the pressure at Venus' surface should be far greater than in our terrestrial atmosphere. But how much greater? A pressure of 10 atmospheres was considered to be the most probable. The Venera-4 spacecraft communicated that the pressure was far greater and was about 20 atmospheres. The temperature on Venus turned out to be unusual. Therefore the instruments mounted on the Venera-5 and Venera-6 spacecraft were designed for higher pressures and temperatures. A more refined radio altimeter was also used. It permitted altitude readings not just at a single point (as on the Venera-4 spacecraft) but at a series of points, which of course permits "tying in" any measurement to an altitude level and constructing a map from them, figuratively a so-called "model atmosphere" (i.e., the altitude distribution of pressure, density, temperature, and chemical composition). Therefore the main purpose for launching the Venera-5 and Venera-6 spacecraft was to increase the accuracy of measurements of the chemical composition along with the atmospheric parameters indicated above and the altitudes corresponding to them as well as to increase the penetration depths of the spacecraft into Venus' atmosphere. In connection with this the housing of the spacecraft's descent stages was strengthened so that it could withstand an external pressure not only as high as 25-27 atmospheres but much higher. The main parachute's area was decreased in order to increase the descent stage's rate of descent in Venus' atmosphere by a factor of 4.

Both spacecraft, each 405 kg in mass, entering Venus' atmosphere at a velocity of 11.2 km/sec at an angle of about 65° to the local horizontal. The rate of descent of the descent stages was lowered to 210 m/sec for a brief time due to aerodynamic braking. After this the parachutes (drag and main) opened, and scientific measurements began in the planet's atmosphere, continuing for more than 50 minutes. Just as in the case of Venera-4, the descent of these spacecraft was accomplished on the nighttime side approximately 2,700 km from the morning terminator and approximately 300 km from each other. The spacecraft penetrated 7 km deeper into the atmosphere than Venera-4, and 20 km deeper than the "radio occultation" level of Mariner-5. During the entire descent measurements were made of the pressure, temperature, and density with a tie-in of these quantities to altitude above Venus' surface. The results obtained not only confirmed the Venera-4 data but also permitted refining them. According to the spacecrafts' data, the concentration of carbon dioxide gas in the planet's atmosphere reached 93-97%, while a value of 90% was obtained from measurements of the Venera-4 spacecraft. The nitrogen content along with the inert gases amounted to 2-5%, and the amount of oxygen did not exceed 0.4%. The measurements of the Venera-4 spacecraft showed that the nitrogen content in the planet's atmosphere was less than 7%, and that of oxygen less than 1%. The water vapor content derived by the Venera-4 spacecraft at levels corresponding to a pressure of approximately 0.6 atmospheres lay within the limits of 1-8 milligrams of water vapor per liter of atmosphere, and the measurements of the Venera-5 and Venera-6 spacecraft showed that the water vapor content at an altitude level corresponding to a pressure of 0.6 atmospheres was from 4 to 11 milligrams per liter. This result indicates that Venus' atmosphere is not saturated with water vapor. The pressure and temperature measurements were carried out on the average for 40-50 seconds. More than 70 pressure measurements and 50 temperature measurements were made during the descent of each spacecraft by parachute. Due to this the temperature and pressure and Venus' atmosphere were measured at every step of the sounding with an accuracy of several percent. /95

The Venera-4 spacecraft made measurements along a stretch where the temperature increased from 25 to 320°C and the pressure from 0.5 to 27 atmospheres. The variation of temperature with altitude in the measurement interval differed little from the adiabatic distribution. On the basis of data derived for the temperature, pressure, and chemical composition, the sections of the spacecrafts' descent in Venus' atmosphere along which the measurements of atmospheric parameters were carried out from the times at which the main parachutes were opened were calculated. The differences between the altitude values recorded by the radio altimeters were in good agreement with the calculated values computed by two independent methods: from the rate of descent of the descent capsule by parachute and from the condition of hydrostatic equilibrium of the atmosphere. The section of the measurements of atmospheric parameters for the Venera-5 spacecraft amounted to 36 km, and for the Venera-6 spacecraft it was 38 km. Based on the preliminary data, the altitudes recorded by the spacecrafts' radio altimeters at identical temperature and pressure values differed from one another by 12-16 km. According to the radio altimeter data of the Venera-5 spacecraft, a pressure of 27 atmospheres corresponded to an altitude of 24-26 km, but according to the radio altimeter data of the Venera-6 spacecraft, the same pressure corresponded to an altitude of 10-12 km. Since the pressure of 27 atmospheres recorded on both spacecraft corresponds to one and the same level in the atmosphere, and the descent occurred above different regions of the planet's surface, then a probable explanation for the difference in the radio altimeter readings of the Venera-5 and Venera-6 spacecraft might be the existence of significant inequalities in the surface relief on Venus. /96
Actually, we also observe on Earth differences in the surface level as large as 20 km (the Himalayas and the Marianas trench in the Pacific Ocean). There is no liquid water on Venus, but the inequalities in relief may be of the same scale as on the Earth. The results of experiments which have been carried out have once more confirmed that Venue possesses an extensive dense atmosphere and has

very high values for pressure and temperature at its surface. If the planet's temperature varied according to the adiabatic law right down to its surface, then the temperature would be about 400° and the pressure of the order of 60 atmospheres at the surface level determined by the radio altimeter of the Venera-6 spacecraft, but at the surface level determined by the radio altimeter of the Venera-5 spacecraft the temperature and pressure would reach, respectively, values of the order of 530°C and 140 atmospheres.

Thus the Venera-5 and Venera-6 spacecraft transmitted data from deeper layers of the atmosphere than Venera-4. They permitted a significant refinement by means of direct measurements of the chemical composition of Venus' atmosphere and obtaining important profiles of its temperature, pressure, and density over a section of about 40 km in depth, which exceeded the intervals of the preceding measurements.

The Soviet scientists M. Ya. Marov, M. K. Rozhdestvenskiy, and V. S. Avduevskiy calculated that if the temperature varies according to the adiabatic law down to the surface, then the temperature and pressure would be 770°K and 100 atmospheres, respectively, with possible deviations of ±60°K in temperature and ±40 atmospheres in pressure, at the mean surface level defined as the arithmetic mean of the radio altimeter readings of both spacecraft. But there is reason to suggest that due to the intense absorption in the lower layers of Venus' atmosphere by gas and dust the temperature gradient will gradually tend to zero. Then the temperature at the planet's surface is 685 ± 10°K and the pressure is 110 ± 50 atmospheres.

In order to make measurements below the level reached by the Venera-5 and Venera-6 spacecraft and to accomplish a landing on the burning hot surface of the planet, the Venera-7 unmanned spacecraft was launched to Venus on August 17, 1970. After a 120-day flight, which covered a distance of about 320 million kilometers, the spacecraft reached the target planet on December 15, 1970, and its descent stage completed for the first time a landing on Venus' surface (Figure 23). Since the preceding measurements by the Venera-4, Venera-5, and Venera-6 spacecraft showed that the planet's atmosphere was very hot, it was advisable to reach the still uninvestigated regions as quickly as possible. In order to provide the most favorable temperature conditions for the descent stage of the Venera-7 spacecraft along the main terminal portion of its descent and at the planet's surface, the design of the descent stage's parachute system was subjected to significant changes, and due to this, the Venera-7 spacecraft passed through the upper regions of the atmosphere significantly more rapidly than its predecessors. In order to measure the temperature and pressure in the planet's atmosphere, a special instrument was installed on the descent stage of the Venera-7 spacecraft which permitted measuring the temperature in a range from 25 to 540°C and the pressure from 0.5 to 150 atmospheres (Figure 24). Based on the moisture content in the atmosphere's upper layers, the condensation level of water vapor was determined, i.e., the lower boundary of the cloud layer, which is located approximately 60 km from the surface (we note that on Earth the main mass of clouds is located at an altitude of only a few kilometers from the surface); one can assume that the thickness of Venus' cloud layer is no less than 8-10 km. Irregardless of th fact, there is very little water on Venus, and it is all located in the atmosp re. The depths of Venus' atmosphere was determined

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on the basis of the radio altimeter readings. In particular, the measured distance from the planet's mean surface level to the descent stages when they reached the zone where the pressure is about 1 atmosphere (i.e., the pressure which occurs at the surface of the Earth) was approximately 52-53 km. Venera-7 conducted a sounding of the atmosphere from an altitude of 55 km to the surface and functioned on the surface for 23 minutes. The spacecraft's rate of descent was measured from Earth by means of the Doppler variation of the frequency of radio waves continuously emitted by the spacecraft's radio instrumentation. For the first time in the history of space exploration a direct transmission of scientific information was carried out from the surface of another planet. The data obtained from the station permitted establishing reliably that Venus possesses an exceedingly extensive strongly heated atmosphere. At the spacecraft's landing site the atmosphere's temperature was 475 ± 20°C and the pressure was 90 ± 15 atmospheres. The gas density at the planet's surface was 60 times higher than the gas density of our terrestrial atmosphere and, consequently, only 17 times less in all than the density of water. /99

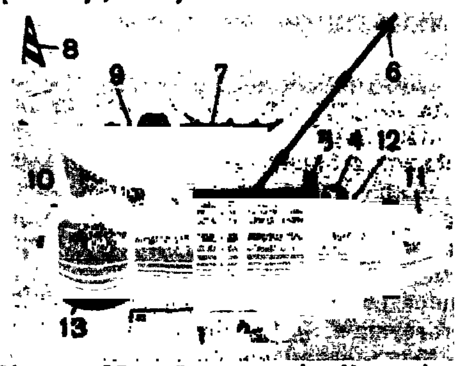
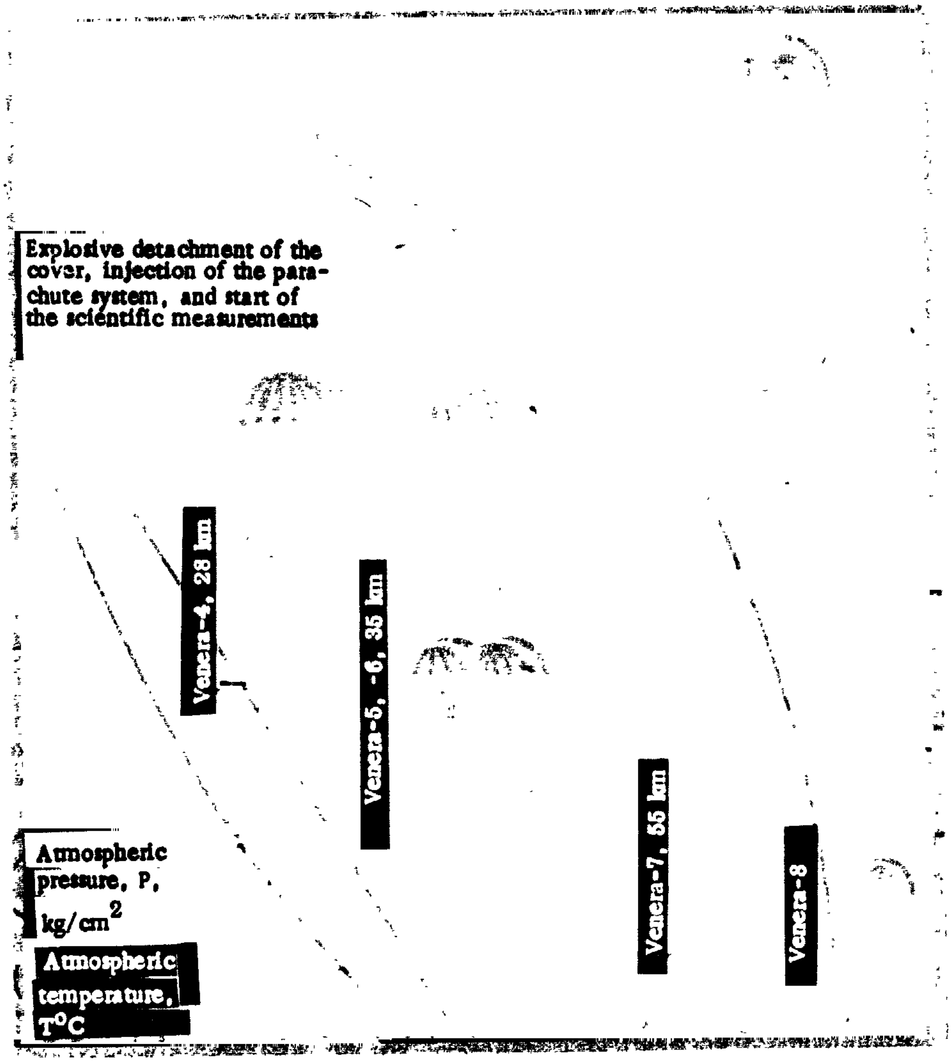


Figure 23. Descent in Venus' Atmosphere of the Venera-4 Through Venera-8 Unmanned Interplanetary Spacecraft: 1, Orbital compartment; 2, Star orientation detector; 3, Constant solar orientation detector; 4, Gas tank; 5, Sun-Earth orientation detector; 6, Detector and magnetometer boom; 7, Narrow-beam parabolic antenna; 8, Slightly directional antenna; 9, Radiator of the thermoregulation system; 10, Solar battery panel; 11, Correction motor assembly; 12, Micromotors of the star orientation system; 13, Descent stage.

The year of the Fiftieth Anniversary of the formation of the Soviet Union was commemorated by a remarkable new achievement in the investigation of Venus. On July 22, 1972 the Venera-8 unmanned spacecraft after a 117-day flight, having completed its 4-month interplanetary journey, carried out for the first time a soft landing on the side of the planet illuminated by the Sun. In order to complete this truly unique experiment by Soviet scientists and engineers, it was necessary to solve a number of completely new problems. First of all, as the spacecraft approached Venus, it was illuminated only by its narrow crescent — about one-tenth of the disk. The maximum diameter of the landing region did not exceed 500 km. If the smallest deviation had occurred in the flight path, the spacecraft would have "bounced" and gone back into outer space or it would have "venused" [Translator's note: this is a play on the word landed] on the nighttime side. In case of too steep an entry into the planet's atmosphere it would have been destroyed as the result of the large overloads, and in the case of an unnecessarily shallow entry it would have flown past the planet.



During the descent from an altitude of 55 km and down to the planet's surface, measurements were carried out of the temperature and pressure. It was established that no significant differences in the altitude distributions of temperature and pressure were detected on the daytime and nighttime sides. At the landing site of the Venera-8 spacecraft, the temperature was 470°C ± 8°C, and the pressure was about 90 atmospheres. These data are very similar to the values obtained by the Venera-7 spacecraft. One of the main problems of landing on the side illuminated by the Sun consisted of determining whether or not sunlight penetrates to the planet's surface or is almost completely blocked by the atmosphere and the clouds. In brief, the question was whether it is light on Venus in the daytime or obscured by darkness. For this purpose measurements were carried out of the illumination in the atmosphere and on the planet's surface. In order to solve this complex problem a special device — a photometer — was mounted on the spacecraft. It permitted measuring the illumination over a wide region of the solar spectrum.

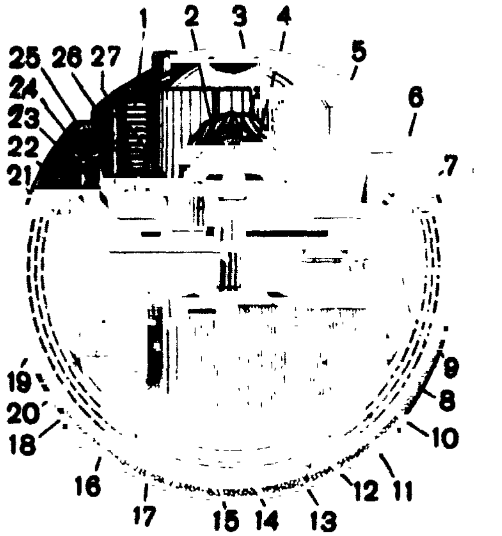


Figure 24. Layout of the Descent Stage: 1, Drag parachute; 2, Main parachute; 3, Cover of the explosive charge; 4, Transmitting antenna; 5, Densitometer detector; 6, Grooved charging vent; 7, Dessicant; 8, Ventilator of the thermoregulation system; 9, Pressure vent; 10, Commutation unit; 11, 16, Acceleration detectors; 12, Transmitter; 13, Mechanical oscillation damper; 14, Power supply; 15, Onboard transmitter; 17, Time-programming unit; 18, 19, 20, Units of the external heat protection design; 21, Internal thermal insulation; 22, Thermoregulation system; 23, Descent stage's housing; 24, Explosive charge; 25, Cover of the parachute compartment; 26, Radio altimeter antenna; 27, Gas analyzer.

On the basis of the information obtained the scientists concluded that a certain fraction of the solar radiation in the visible spectral region penetrates to the planet's surface, and noticeable differences exist there with respect to illumination in the daytime and at night, namely, Venus' atmosphere significantly weakens the sunlight.

Using a special device the ammonia content in Venus' atmosphere was measured. It was established that its volume content lies within the range 0.01 to 0.1%.

Upon the spacecraft's descent the horizontal wind velocity was measured. At altitudes of about 45 km it was greater than 50 m/sec, and at an altitude of 10-12 km it dropped to 2 m/sec.

These measurements confirm the presence of a zonal (latitudinal) wind directed from the terminator towards the daytime side, i.e., in the direction of Venus' intrinsic rotation, and they have important significance for understanding the atmosphere's dynamics. /100

A large role in the program of the planet's in[illegible]ations was assigned to the study [illegible] physical-chemical properties of the planet's surface. Information [illegible] obt[illegible]d about the dielectric const[illegible] density of the soil from an a[illegible] the level from which radio wa[illegible]ted by a device during the des[illegible] process were reflected. The results of these measurements offer a reason to assume that at the descent site the planet's surface layer is rather friable with a soil density much less than one and one-half grams per cubic centimeter.

The results of a measurement of the content of natural radioactive elements in the surface layer of Venus at the spacecraft's landing site have great significance. It is possible to determine the nature of a rock from its total chemical and mineralogical composition. Moreover it is possible to get an idea as to the nature of a rock from the set of individual chemical elements which are sufficiently characteristic of this or the other type of rock. For example, from the content in the rocks of the natural radioactive elements: uranium, thorium, and potassium. Therefore a gamma-ray spectrometer was mounted on the spacecraft which determined the content of radioactive elements in Venus' surface layer from their gamma-radiation. An instrument was mounted inside a simulator of the Venera-8 spacecraft to approximate the measurement conditions to the actual conditions of the experiment on the planet. The measurements were carried out on granites, basalts, and other rocks. In addition the spacecraft's intrinsic background was measured above a fixed outcrop which had an exceedingly low content of natural radioactive elements. This background was caused by gamma--radiation of natural radioactive elements present in the form of minute impurities in the construction materials of the spacecraft and the instrument. Three measurements were carried out of the integrated intensity of gamma--radiation upon the spacecraft's descent in Venus' atmosphere, and one measurement was made after its landing on the surface. The intensity recorded during the descent did not vary by a noticeable amount, which indicates the virtual absence of a contribution of emissions due to short-lived isotopes formed under the influence of cosmic rays during the spacecraft's flight in outer space.

After the descent stage's landing an increase was recorded in the integrated gamma-ray spectrum. All the information from the spectrometer was completely decay of natural radioactive elements contained in Venus' surface layer.

During the time of the spacecraft's active presence on Venus' surface (50 min), the transmission of information regarding the atmospheric parameters (temperature, pressure, illumination, wind velocity, and ammonia content) and the characteristics of Venus' soil was carried out. Measurements were made of the gamma-ray spectrum. All the information from the spectrometer was completely read out twice. Measurements of the gamma-ray spectra permitted carrying out /101 a quantitative determination of the uranium, thorium and potassium content in the surface layer. Based on the preliminary data, the surface material at the spacecraft's landing site contained 4% potassium, 0.0002% uranium, and 0.00065% thorium, reminiscent in, content, of radioactive elements and, with regard to their ratio, of the composition of terrestrial granites. Thus the Venera-8 spacecraft discovered a rock relatively rich in potassium, uranium, and thorium. Under terrestrial conditions such a ratio of the elements, especially the relative richness of potassium, is characteristic of rocks which have been subjected to secondary alterations under the influence of different factors of the surrounding medium after an initial extraction from the planet's interior. These data are a very valuable contribution to the study of Venus' geology. It is true that they were obtained only for a small region of the planet's surface; however, subsequent investigations will permit covering other regions and drawing sufficiently specific conclusions as to the processes which have occurred in the solid envelope of Venus and the nature of its evolution.

During the flight in interplanetary space, an increase of solar activity was recorded by the spacecraft — four powerful solar flares. Measurements were made of the ultraviolet radiation produced by the neutral atomic hydrogen dispersed in interplanetary space. Its intensity increased by a factor of 2-3 at some points of the flight trajectory. In addition the radiometric instrumentation mounted on the spacecraft permitted investigating the dynamical processes in interplanetary space associated with solar activity. The confirmation and refinement of the temperature and pressure information obtained earlier was exceedingly important. It turned out to be unbearably warm on Venus' surface, and the pressure was exceedingly high.

And so good-bye to most beautiful dream about a greenhouse planet — the younger sister of the Earth! The unmanned spacecraft have overturned the most attractive prediction and shown that it is oppressively hot on Venus, there are no oceans, and there are probably none of the life forms known to us. Evidently a difference in the evolutionary processes occurring on the neighboring planets, Venus and Earth, resulted in such a significant contrast in the physical-chemical characteristics of their atmospheres.

Why does Venus' surface have such a high temperature? It is easiest to explain this by the effect of the greenhouse mechanism, which should operate far more effectively on Venus than in the Earth's atmosphere. In fact it is approximately one-third nearer to the Sun than is the Earth! The mixture of carbon dioxide gas and water vapor causes a very strong screening effect on thermal radiation. This effect increases significantly as the temperature and pressure increase.

But the high temperature, the large atmospheric pressure, and the significant carbon dioxide gas content — are these factors connected with each other or not? Undoubtedly, asserts the eminent Soviet scientist A. P. Vinogradov. The high temperature facilitates the conversion of carbonate rocks into silicates with the liberation of carbon dioxide gas. On Earth the carbon dioxide gas is bound up and converts into sedimentary rocks as the result of the action /102
of the biosphere, which is absent on Venus. On the other hand, a large carbon dioxide gas content facilitates the heating up of Venus' surface and the lower layers of its atmosphere. On the Earth water and carbon dioxide are contained in the Earth's crust in the bound state, and on Venus they "wander". If we raise up into the air all the bound carbon dioxide gas, the atmospheric pressure would increase by a factor of 40! Then it would appear to be similar to Venus' as far as composition and pressure is concerned. Of course, the analogy cannot be complete. Everything must be far more complicated. The carbon dioxide gas which exists in the Earth's atmosphere is the product of the vital activity of plants and animals. In addition, carbon dioxide gas is removed from the atmosphere due to purely chemical reactions. The fate of carbon dioxide gas on Venus was different. Venus is closer to the Sun, and therefore it is heated up more strongly. Independent of the other circumstances, this would cause the transition into Venus' atmosphere of large amounts of water and carbon dioxide. Carbon dioxide, due to its physical-chemical properties, is able to absorb solar heat and the heat emitted by the planet in the form of infrared radiation. This has resulted in the self-heating of the gaseous envelope and surface of Venus, which has evidently prevented the appearance of life.

Scientists assume that in contrast to Jupiter and Saturn, where the primary atmosphere is retained consisting of gases liberated directly by the Sun, on Venus (as on the other terrestrial planets) the atmosphere is of secondary origin as the result of the degassing of material upon the planet's being heated up.

Another thermal exchange mechanism — the deep circulation model — is based on the assumption that sunlight cannot reach the surface but is completely blocked by the atmosphere and clouds. In this case the heating up of the low-lying atmosphere could occur due to the adiabatic compression of the gas upon its sinking into the atmosphere's lower layers. The fact that the altitude distribution of temperature is similar to an adiabatic distribution right down to the surface was discovered from the results of measurements made by the Venera spacecraft. However, this fact fits well into the ideas of the greenhouse model. Therefore, in order to make a choice between the two models, it is necessary to know how the weakening of sunlight occurs below the cloud layers visible from Earth. It is, of course, impossible to exclude the possibility that the planet's internal heat plays a definite role in Venus' thermal system.

It is necessary in this and in the other model to assume an important role for circulation on Venus, which equalizes the temperatures between the daytime and nighttime sides and between the equator and the poles.

The creation of spacecraft and scientific and engineering equipment, which have fulfilled under extremely difficult conditions their assigned tasks was clear evidence of the correctness of the design solutions and is a new important achievement of space technology. This will help later on to design with even more assurance the subsequent generation of Venus spacecraft. However, irregardless of the fact that the values of some atmospheric parameters /103
were measured with an accuracy of 1% and we can assess with sufficient assurance the physical conditions on Venus, all the same, the explained cause for the sharp difference between the conditions on Venus and those on the Earth remains. What kind of processes led to the formation of such an extensive carbon dioxide atmosphere? The basic mechanism leading to a lack of water on Venus is not clear. What explains the very high temperatures and pressures on Venus' surface? What are the structure, composition of Venus' clouds, and their dynamics in its atmosphere? Why does the upper atmosphere rotate approximately 60 times more rapidly than the planet itself? What is the mineralogical composition of the rocks composing Venus, and what occurs on its surface?

These and other questions continue to disturb people. In order to solve these problems of a fundamental scientific nature, it is necessary to conduct a combination of investigations, both with the help of space technology and with the help of ground-based observations.

A project to investigate Venus' atmosphere with the help of aerostats floating in it, which has not once been mentioned in the press, seems very interesting. They would be able to reveal many interesting phenomena and processes occurring in Venus' atmosphere, namely: refine the chemical composition and physical conditions in the cloud layer; obtain information about the winds at the aerostats' drift altitude; measure the time variations of the atmosphere's parameters; and clarify whether or not there are living organisms in the cloud cover of Venus, and so forth.

The creation of artificial satellites of Venus is a very attractive idea. And, although they will be less effective than, let us say, satellites of Mars, due to the impossibility of using television cameras for obtaining an image of the surface relief, nevertheless it will be possible with the help of a radar system, the so-called synthesized aperture, to obtain an image of Venus' surface.

There is no doubt of the necessity of creating such devices, which, having descended to Venus' surface, would deliver to it special mobile devices of the Lunokhod type. These devices, moving about on Venus' surface, would help people obtain reliable answers to the questions which interest us today.

But until the time at which these experiments become an actual reality, it is necessary all the same to recognize what the surface of Venus is like. In connection with this scientists from a number of countries have suggested photographing Venus' cloud layer from an aerostat which a spacecraft should eject. After completion of the surveys during the aerostat's flight above the clouds, a capsule with a television device should be uncoupled and, descending onto the planet, carry out a survey of its surface. The aerostat and the spacecraft — satellite of Venus would serve as the relay stations for transmission of images to Earth.

It is undoubtedly necessary to investigate directly on the planet's surface the soil of Venus, since returning it to Earth represents a very complicated problem: too great an atmospheric thickness which it would be necessary to /104
overcome during a take-off from the surface, and the pressure of 100 atmospheres requires the creation of motors with rather exotic parameters.

What Awaits Man on Venus?

"...What awaits man on Venus has already been written about in a good hundred novels — and all differently. It is not up to me to make the one hundred and first guess," wrote the first cosmonaut of the Earth Yuriy Alekseyevich Garagin. I only believe that man will with persistence and desire find how to change the weather conditions of Venus so that it becomes possible to make this puzzling planet inhabitable."[11]

It is very likely that the greenhouse effect made Venus too inhospitable. But is it possible to make Venus inhabitable? Yes, answer the scientists, it is possible if we eliminate the main cause of the greenhouse effect. In order to do this, it is necessary to cleanse it of the excess of carbon dioxide gas and water vapor. Having eliminated them, the atmosphere will cease to be a trap of solar heat. When this thermal effect decreases, the temperature will drop, the water vapor will condense into water, and this will decrease the greenhouse effect all the more, and then conditions may be created on Venus which are favorable to the development of the animal and vegetable world. But how can this be done?

The Soviet scientist D. Martynov and the American astronomer C. Sagan have suggested independently of one another carrying out a very bold space experiment. They assumed that it is possible to change the climate of Venus. In fact there is everything necessary for photosynthesis in its atmosphere: carbon dioxide

[11]Yearbook of the APN, "In the Year 2017".

gas, solar radiation, and water vapor. Therefore in the upper, relatively cool, layers of its atmosphere, which they assume are saturated with water vapor, terrestrial single-celled algae and other microorganisms might have developed similar to the way in which they develop near the surface of the terrestrial ocean. In the process of their vital activity, they would liberate, intensively reprocessing the carbon dioxide gas, free oxygen. Layers of solid organic compounds and carbonates would begin to precipitate to the bottom of the atmosphere onto Venus' surface. Once it had started, this process would be propagated in avalanche fashion. Each percent of oxygen annihilated would lower the temperature several degrees. The thickness and "greenhouse" properties of Venus' atmosphere would finally be diminished to the point that the greenhouse effect would no longer be able to play a significant role. Liquid water would appear, and the temperature would drop to such an extent that specially developed forms of microorganisms and bacteria, and then plants, would now be able to multiply on the surface itself. They will help complete the matter — converting Venus' atmosphere into a new state, the first polar regions, and then the entire surface of the planet would cool off to the point that man will be able to live there.

But prior to accomplishing this truly daring experiment it is necessary, /105 assert the authors of this attractive hypothesis, to establish whether or not there is any life on Venus. In fact it is not excluded that within the upper layers of Venus' atmosphere there exist unusual "atmospheric plankton" — flying and soaring microorganisms. As a result of a biological invasion they may perish or enter into single combat. Therefore if even the simplest microorganisms are encountered there, then it is necessary, prior to embarking on such a grand experiment, to study them. Today we must assume that the conditions on Venus are unsuitable for people.

Days on Venus

Few of the puzzles about Venus have excited such arguments among astronomers as the question of its axial rotation. The scientists were divided even as to whether or not it rotates counter-clockwise or clockwise, and the duration of a single revolution was according to different estimates from 24 hours to 225 terrestrial days, i.e., an entire Cytherean year! Alot of interest in this question has been aroused by the fact that the period of rotation and the value of the inclination angle of its equator to its orbital plane determine the duration of day and night on Venus and the change of the seasons. Why was it so difficult to determine Venus' rotation? The answer lies in the fact that the dense cloud covering did not permit noticing anything on its surface, a spot or some kind of point, from which it would have been possible to determine the nature and period of the planet's rotation. Attempts to determine this from the motion of features on its disk, both in the visual and in the ultraviolet radiation, and also from the displacement of spectral lines gave contradictory and unconvincing results. Only radar measurements, begun in 1961, permitted at first approximately, and then more accurately, determining not only its period of rotation but also the direction and speed of the rotation.

Great credit in this matter belongs to a group of Soviet radio physicists headed by Academician V. A. Kotel'nikov. Their results introduced complete clarity into this very confused question, which has a long history.

It turned out that in contrast to the Earth, Venus rotates about its axis very, very slowly. Its intrinsic rotation period is 243.0 ± 0.1 terrestrial days.

The duration of a day, i.e., the succession of day and night, on Venus is equal to 117 terrestrial days, and the Cytherean day (from sunrise to sunset) lasts almost 2 terrestrial months. It is curious that if a year lasts 225 days on Venus, then there are 56 days in each of the 4 times of year, which means that each season on this planet lasts approximately one-half a Cytherean day.

During the Cytherean year (i.e., during one revolution of Venus around the Sun) our Sun rises and sets twice on the planet.

In contrast to the Earth, Venus rotates in the reverse direction, i.e., /106
clockwise if one is looking down from the planet's north pole. Due to this it appears that cosmonauts located on its surface would observe the rising Sun in the west and the setting Sun in the east. They would be able to observe at almost all latitudes twice a year something akin to "polar night" and "polar day" with a duration of about two of our terrestrial months. Such an unusual rotation for the planet gives rise to one more completely unexpected characteristic: upon its nearest approach to the Earth, when the Sun, Venus, and the Earth are "formed up" in a straight-line and the distance between the Earth and Venus standing opposite it is a minimum, Venus has one and the same hemisphere turned towards the Earth. Such synchronous direct glances, "eye to eye", are repeated every one and one-half years. It is as if the Earth leads Venus on a string. Why does Venus rotate in the reverse direction? Some cosmogonical theories suggest that this occurs due to the planet's "youthful age". The observed evolution of Venus' orbit will establish in several hundred thousand years a "cosmic" harmony, and it will begin to rotate in the same way as its remaining older neighbors. The young age of Venus incidentally is very attractive to scientists. In fact the possibility is not excluded that it is repeating in its development the path followed by the Earth?!

An Optical Miracle

If a person in some way were to end up on Venus and look around, he would see that the horizon in the usual sense of the word does not exist; it would seem to him that he located at the bottom of a gigantic bowl into which are projected (of course, in a greatly distorted form) even the very distant regions of the planet. The horizon would appear to him to be raised up in all directions.

Such unusual optical conditions occur in the lower layer of the atmosphere due to the high light-refracting ability of the strongly compressed carbon dioxide gas, which even at normal pressure possesses a rather large light-refracting ability. It passes through a multitude of layers of carbon dioxide gas of different density prior to reaching Venus' surface. This means that the

refraction will be multiple, and a ray will in fact follow not a straight-line but a curve. The deflection will be turned with the convexity upward (with respect to a straight-line joining the Sun and the observer). Therefore the horizon will be displaced and will move upward. The level surface will seem like a funnel or pit on the bottom of which the observer is located. This phenomenon, the so-called "superrefraction", is maintained up to a certain limiting altitude of about 12 km. Above this the light rays now encircle the entire planet. Therefore, located at this altitude and looking forward, this hypothetical person would in principle be able to inspect the back of his own head. Clouds and the dense atmosphere greatly weaken the sunlight; therefore the illumination of the planet's surface is not very great. It most probably /107
corresponds to our twilights on a cloudy day.

It is interesting to note that as the observer's elevation increases, his range of visibility decreases, which would appear to him to be a straightening of the planet's concave surface. All this would be just the same if Venus' atmosphere were transparent. However, an observer would not see the Sun in the daytime or the star-filled sky at night due to the fact that Venus is covered by dense continuous clouds. The illumination measurements in the planet's atmosphere and at its surface carried out by the Venera-8 spacecraft indicate that sunlight, although it is greatly weakened by the atmosphere and the clouds, penetrates right down to the planet's surface.

Times of Year and the Climate on Venus

As the radar observations indicate, Venus' axis of rotation appeared to be close to perpendicular to the ecliptic plane (87°!). Therefore seasonal variations like those on Earth are practically absent on Venus. There is no winter, summer, fall and spring on Venus. Since its axis of rotation is almost perpendicular to the plane of its orbit, climatic belts occur on Venus, but in each of them it is always the same time of year. The climate gradually becomes more severe, but not in time but in space — from the equator to the poles.

Accurate spectroscopic investigations of Venus' cloud cover, and also observations of the motion of certain dark spots in its cloud cover, have indicated a period of rotation of about 4-5 terrestrial days. What is going on? The planet rotates very slowly as a solid body, but the cloud cover (the upper part of its atmosphere) rotates 50-60 times more rapidly. If this is so, then winds of hurricane speed (up to 100 m/sec) prevail at the cloud level in the atmosphere of Venus.

Measurements by the Venera-8 spacecraft showed that the horizontal component of the wind velocity varies greatly with altitude: at altitudes higher than 45 km it exceeded 50 m/sec, but below 10-12 km it decreased to 2 m/sec.

Now astronomers propose a model of the entire atmosphere of Venus. And this is already a significant step in our knowledge of the physical processes in its atmosphere. However, irregardless of the fact that Venus has recently been subjected to a real scientific storm, nevertheless it does not pay to be seduced, as many puzzles yet remain, and new questions have arisen.

In the course of investigating Venus, scientists have encountered a curious fact: the temperature on the daytime and nighttime sides of Venus are practically equal. This is very strange. In fact the days on Venus are very lengthy. During the day the planet's surface should be heated up very greatly, and during the night, it should cool off, even in spite of the dense atmosphere. Academician V. G. Fesenkov has explained this strange fact as due to the fact that on Venus the winds probably blow constantly in a latitudinal direction, smoothing out the temperature differences.

However, the complex atmospheric structure of Venus has still not been investigated up until now. Let us assume that it consists of a lower atmosphere, a cloud layer, and an ionosphere in which powerful convective motions occur. /108

Let us assume that in contrast to Jupiter and Saturn, where the primary atmosphere of gases liberated directly by the Sun has been preserved, the atmosphere on Venus (as on the other terrestrial planets) is of secondary origin as the result of the degassing of material upon the planet's being heated up. At the present time scientists assume that its heating up is associated with the absorption in Venus' atmosphere of solar radiation.

Concerning water, an analysis of the data obtained shows that the water vapor content is small in the lower layers of the atmosphere, at least a thousand times less than on Earth. Evidently water condenses in Venus' cloud layer, although the question of the composition of these clouds and also their vertical thickness still remains unsolved. Scientists have come to a curious conclusion: although the weather on Venus is always cloudy and overcast, rainfalls evidently never occur there. The solar radiation does not always penetrate through the dark-gray veil of dense clouds and does not play with a heavy light spot on the surface of this planet, which is still inhospitable to human life. Venus is a completely, special amazing world full of mysteries and unexpected characteristics.

CHAPTER 5.
INTERPLANETARY TRAJECTORIES /109

Characteristics of Interplanetary Flights

The significant difference between flight in outer space and in the atmosphere lies in the characteristics of the use of energy (fuel). In order that an airplane be able to move, its power plant must operate continuously. If it is turned off, the airplane starts to descend, and then land. Flight in space is completed quite differently. There the resistance of a medium is absent, and the spaceship, having reached a specified velocity, will keep moving by inertia outside the spheres of activity of the planets.

A second important difference lies in the fact that the expenditure of energy depends on the direction of take-off from the Earth and the motion in interplanetary space. In the case of an airplane's flight, it is absolutely immaterial whether it flies north or south, east or west — the energy expenditure (fuel) is the same. In spaceflight, on the contrary, the amount of energy expended depends on the direction of flight. Thus, in the case of the launch of a spacecraft in the direction of motion of the Earth the energy expenditure is approximately three times less than when it is launched in the direction opposite to the Earth's motion around the Sun. And since all the planets are moving in the same direction, spaceships flying to the planets should move around the Sun in this same direction. Therefore we observe in space one-way motion.

When traveling over the Earth, and we desire, for example, to stop a moving automobile, it is very simple — we turn off its motor. Under the influence of friction from the Earth and air resistance, it stops. There is no friction in space, and it is necessary to reduce the spaceship's speed to the speed of the target planet. It is absolutely immaterial which of these speeds is greater. /110
In both cases it is necessary to expend energy, namely: if the planet is moving more rapidly than the spacecraft, then it is necessary to catch up with it, but if it is moving more slowly, then on the contrary it is necessary to decelerate. Therefore a double energy expenditure is required in fact in interplanetary flight: to put the spacecraft into motion and to decelerate it or speed it up upon its approach to the target planet.

Interplanetary space is almost an absolute vacuum, which is very favorable to interplanetary journeys. Actually, would spacecraft really be able to attain the velocities necessary for flight to other celestial bodies in a dense medium? Even if they moved at low speed, their time of flight, for example, to the nearest planets would be excessively great, and the fuel expenditure would be truly incredible. Thus in the case of a spacecraft's motion in a dense medium with motors functioning and a constant speed of one kilometer per second, it would be necessary to consume up to to two million tons of fuel per one kilogram of mass just in order to send it out of the Earth's sphere of influence. But even if oxygen were in space and its density was sufficient to provide the motors with free oxidizer, all the same an enormous amount of fuel would be required, which it would be necessary to carry onboard the spacecraft due to the long duration of the flight and the necessity for the continuous operation of the motors. Thus on the one hand interplanetary flight is a medium "hostile" to man, requiring special means for his protection from the vacuum, meteoric objects, and cosmic radiation, but on the other hand, it is a very favorable medium for achieving the necessary velocities with spacecraft to carry out interplanetary flights.

The interplanetary trajectories extend in outer space for hundreds of millions and billions of kilometers. This places special requirements on the size and direction of the initial velocity transmitted to the spacecraft upon its launch and entry into its interplanetary trajectory. As calculations show, even in the case of a flight to the nearest planets, an error in the initial velocity of only one meter per second in all or a deviation in the velocity vector from the required direction by one minute of arc results in a miss of the target of tens and even hundreds of thousands of kilometers. In fact after the auxiliary power plant spurring the spacecraft onto its necessary velocity ceases operation, it flies in outer space, subject to the laws of celestial mechanics, i.e., obeying only the laws of gravitation of celestial bodies. In contrast to terrestrial means of locomotion, a spacecraft does not move either rectilinearly or uniformly. The large distance to the planets and their relatively small sizes hinder greatly a spacecraft's reaching the target planet without a correction of its flight path. Therefore so that the spacecraft can enter the desired region of the target planet's location, a correction maneuver is necessary. For this the spacecraft should in advance of the calculated time be oriented, with the help of devices, to celestial objects, assuming the desired position in order that the impulse of the onboard correction motor /111
is communicated in the necessary direction. The size of the necessary additional velocity communicated to the spacecraft is provided by a specified duration of the motor's operation. But in order to complete such a maneuver, it is necessary to measure the trajectory parameters of the spacecraft's motion with the help of ground-based radar means. These data are combined with the calculated data, and on the basis of these figures, a prediction is made of the spacecraft's motion and a correction of its flight path is made.

For a journey on Earth with any kind of transport, we select the shortest route as near as possible to a straight-line joining the departure point to the arrival point. Such a route is under ordinary conditions the most favorable from the point of view of time expended and energy required.

In the case of interplanetary flights, on the contrary, the shortest route requires the largest energy expenditure. Therefore the trajectories most favorable from the point of view of energy expenditure are those which fly in the direction of orbital motion of the planets. Thus, for example, the length of the interplanetary trajectory in the case of a flight from Earth to Venus for a minimum fuel expenditure amounts to about 400 million kilometers, but the shortest distance between these planets is 39 million kilometers. But for a flight along a straight-line it is necessary to expend three times more fuel than in the case of motion along an elliptical trajectory in the direction of the orbital motion of the planets.

An interplanetary transfer flight so to speak represents shooting a moving target (the destination planet) from a moving platform (the Earth). Such a shooting is carried out at a certain established point located on the orbit of the destination planet at which it should arrive at the instant of the arrival there of the spacecraft. Therefore one of the characteristic features of interplanetary flight consists of the fact that it is impossible to choose arbitrarily the launch date from the Earth. When traveling on the Earth neither a train nor an airplane takes the risk of, having arrived at the goal, not stopping there at the station or the airport. This does not happen even if the airplanes and trains were moving late or at an unforeseen speed. The matter of interplanetary flights is quite different, because the planets are continually moving around the Sun at enormous speeds (the Earth moves at an average speed of 29.8 kilometers per second, and Mars and Venus, 24.1 and 35 kilometers per second, respectively). Due to the different speed of the planets' motion and their distances from the Sun, their mutual position in space continually changes. In order to arrange the encounter of a spacecraft with a destination planet, the time of its launch should be selected in such a way that the mutual arrangement of the Earth at launch and the planet at the "encounter" with it of the spacecraft are completely specified. This condition determines a number of ranges of launch and encounter dates favorable from the point of view of the dynamics of the interplanetary spacecraft. If, based on this, one draws a graph of the flight dates from Earth to Mars or Venus along the most favorable trajectories requiring a minimum fuel /112
expenditure, then a startling result is obtained: these dates will not be distributed uniformly over the months of the year or several years, but they will be grouped into rigorously specified time intervals conventionally called the navigation season. Thus in the case of a flight to Mars such a navigation season covers approximately 100 days, and for a flight to Venus, about 60 days. The most favorable mutual arrangement of the planets for transfer flights periodically repeat. In the case of a flight to Mars — every 2 years and 50 days, and for a flight to Venus, approximately every 19 months, while for a flight to Mercury — every 116 days, to Jupiter — every 400 days, and for a transfer flight to the more distant planets, the periodicity is somewhat longer than one year.

Conditions for the Selection of an Interplanetary Trajectory

The class of interplanetary trajectories is very extensive. It includes trajectories passing near the destination planet which can be concluded with the placement of the spacecraft into an orbit as an artificial satellite of the planet — the goal being a landing on its surface or with a subsequent take-off from it with the purpose of returning to Earth. The flights can be completed both automatically by unmanned spacecraft and by spaceships controlled by a crew. They can be operated both in a momentum mode, upon the supply to the spacecraft of the necessary velocity with the subsequent switching-off of the auxiliary motors and with a continuous or variable thrust force. If to this we add the interplanetary trajectories including the performance of maneuvers in the gravitational spheres of activity of intermediate planets, then the enormous variety of interplanetary trajectories becomes completely evident. They are distinguished from each other according to the mode and duration of the transfer flight, the necessary energy expenditures, the nature of the spacecraft making the flight (unmanned or manned spacecraft), and on the basis of other characteristics.

Since only the principle aspect of the problem of conditions in selecting an interplanetary trajectory is important to us, we will adopt certain assumptions in order to simplify matters, namely: we will assume that the orbits of all the planets are circles located in the same plane and that the orbital speed of the planets is uniform. Actually neither the first, the second, nor the third assumption is true. In actuality all the planets move along elliptical[12] orbits, and because of this their speed is non-uniform. Their orbits are also not coplanar (they do not lie in the same plane), and they are inclined (true, not by very much) to the ecliptic plane and with respect to each other.

The interplanetary trajectory of a spacecraft can have the form of an ellipse, parabola, or hyperbola. The most economical in the sense of energy expenditures (fuel) is a semi-elliptical trajectory tangent to the orbits of the Earth and the destination planet. Besides semi-ellipses tangent to both orbits, the trajectories of interplanetary spacecraft can be segments of ellipses, parabolas, and hyperbolas tangent only to one of the orbits or intersecting both orbits at some angle. /113

Since the planets move in their own orbits at different speeds, it is necessary, in calculating the duration of a spacecraft's possible transfer flight along a specific trajectory, to take into account their mutual arrangement. If we select a flight along a semi-ellipse, assuming that the orbits of the planets are circular, we will find for the difference in their heliocentric longitudes l_1 and l_2 at take-off:

$$\pm(l_1 - l_2) = 180° - n\,(t_1 - t_0),$$ [13]

where l_1 is the longitude of the outer and l_2 is the longitude of the inner planet, n is the mean daily motion of the planet to which the transfer flight is directed and t_0 and t_1 are the epochs of take-off and landing of the spacecraft. The "plus" sign corresponds to a flight from an inner planet to an outer one.

The conditions expressed by this equation are fulfilled for a specific trajectory only once every synodic period of the planet. Therefore the durations of transfer flight from the Earth to another planet and back are rigorously fixed by the fulfillment of this condition. Even taking into account the possibility of varying the initial speeds and trajectories of the flight, rather extensive "dead seasons" will occur when no kind of spacecraft will be able to be launched from Earth to the given planet or back. For this reason the length of stay on

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[12]Yes, and this is true since the attraction of other celestial objects affects the motion of the planets; therefore their orbits of motion are not exactly elliptical.

[13]In case of the necessity of taking into account the eccentricity of the orbits, the differences between the true anomalies of the destination planet at the epoch t_1 and t_0 should appear in the right-hand side of the equation in place of $n(t_1 - t_0)$.

another planet (in the case of a landing) depends in the final analysis on the speed which the spacecraft will be able to acquire on its take-off from the planet. It is desirable to shorten the time of an interplanetary transfer flight to a minimum. This is especially important for spacecraft with a crew of researchers, since as the flight duration increases, the radiation and meteoric hazard increases. In addition, the more rapidly the interplanetary transfer flight is completed, the fewer supplies are needed for the crew's life support.

The placement of a spacecraft into interplanetary trajectories should be accomplished with the minimum possible energy expenditure for catching up, maneuvers, and correction of the trajectory.

Upon a spacecraft's landing on another planet, it is extremely important that it have a minimum speed as it approaches the planet. In this case the size of the braking impulse, and consequently, the fuel expenditure will be a minimum. The extent of the atmosphere's (if such exists) effect due to heating up the spacecraft because of the aerodynamic resistance of the planet's gaseous envelope will be a minimum. And this will permit decreasing the weight of its construction and thermal protection. The overloads will be less, which is very important in carrying flights with manned spaceships. The time of a transfer /114 flight from one planet to another should provide for carrying out problems in the shortest periods with maximum reliability. In the case of the flight of a spacecraft near a planet, conditions providing for a landing on the planet, the photography of its surface, or carrying out scientific experiments should be fulfilled.

As is well-known, a minimum launch velocity is required to reach any planet in the case of a flight along a semi-elliptical trajectory. However, even with one and the same configuration of the planets the distances between them are constantly changing due to the more or less significant displacement of their orbits. In connection with this, the minimum speed, for example, in the case of a flight to Mars varies within the limits of 11.44 to 11.75 km/sec as a function of the take-off period.

In selecting an interplanetary trajectory, it is impossible not to take into account the flight's duration. This is necessary in order to provide trouble-free operation of the equipment (the reliability requirement), and in a manned flight, stores of water, oxygen, and rations.

One should also take into account the fact that the spacecraft's actual trajectory may deviate from that calculated in connection with errors arising upon the spacecraft's insertion into the interplanetary trajectory. Therefore during the flight the possibility is provided of making a correction, i.e., adjusting the deviations of the actual trajectory from the calculated one.

In selecting an interplanetary trajectory, it is necessary to take into account the distribution in interplanetary space of meteor streams. During an extended space journey the Sun's state also plays a role. Therefore interplanetary flights by manned spaceships must necessarily be accomplished outside meteor streams and preferably during periods of the "quiet Sun". We note that the next period of maximum solar activity will occur in 1977-1979 and the minimum solar activity in 1984-1986. The flight trajectory should maintain specific conditions for observation during the spacecraft's flight and for performing orientation of the spacecraft in space in the course of a correction, during the communication sessions, and during the scientific experiment.

Even a simple enumeration of these basic requirements shows how complex is the choice of an interplanetary trajectory and its computation. It is completely understandable that it is impossible to satisfy simultaneously all these and many other requirements. Therefore it is necessary to compromise, depending on what requirements in each specific case are the most important. The problem consists of selecting a favorable and optimum trajectory which must satisfy the basic requirements and be well-matched with the others.

It is possible arbitrarily to divide an interplanetary trajectory into 3 sections: the initial, the interplanetary, and the terminal. The first so-called active section the spacecraft, overcoming terrestrial gravity, is accelerated under the influence of the motors' thrust force to the speed necessary for a flight to another celestial body. Depending on the acceleration conditions (whether motors of large thrust for launch from Earth or small — from a near-Earth orbit) the spacecraft's flight along this section /115 may last from several minutes to several tens or hundreds of hours. After obtaining the required velocity the motors are turned off, and the second portion of the flight begins for the spacecraft: the spacecraft is literally placed into a "drift". This is the principal portion of the entire flight in extent and duration. During this time the spacecraft moves under the influence of the powerful attraction of the Sun. After its entry into the . where the attraction of the celestial body becomes greater than that of the Sun, the first stage will begin for the spacecraft. It lasts again during the operation of the motors which carry out the deceleration of the spacecraft to a speed which provides for its placement into a near-planetary orbit or overtaking the planet-goal. Timewise the flight along this section (also depending on the deceleration or accelerations conditions) may take from several minutes to several tens or hundreds of hours. Thus during the entire time of the spacecraft's flight, which may last months and years, the motor assembly operates only along restricted (in duration) sections of the flight.

Let us discuss in somewhat more detail the flight of a spacecraft in each of these sections with regard to flights to Mars and Venus.

Flight of a Spacecraft Along the Initial Section of the Trajectory

In order to leave the Earth's sphere of influence and head for another planet, for example, Mars, the spacecraft should have a velocity exceeding the escape velocity. Why? The answer is that if it is accelerated to the escape velocity, which is equal to 11,185 m/sec at the Earth's surface, and then turns off the motors, its speed will continually be diminished as the spacecraft recedes from the Earth. Thus, having receded 10,000 km from the Earth, it will have a speed of 6,983 m/sec, and at a distance of 100,000 km — 2,740 m/sec. When the spacecraft reaches the boundary of the Earth's sphere of gravity, then its entire reserve of kinetic energy will be exhausted and its flight velocity will become equal to zero. Therefore, acquiring the escape velocity along the acceleration section, the spacecraft will be able to overcome the terrestrial attraction, and it will not "fall" back onto the Earth, but it will not fly further. It will move around the Sun together with the Earth.

What is the minimum velocity that it is necessary to impart to a spacecraft in order that it be directed to Mars o Venus? If one assumes that Mars is located at an average distance from the Sun, then, as calculations show, it is sufficient to impart to the spacecraft a velocity equal to 32.7 km/sec, and it will reach the destination planet (Figure 25). This velocity, as is not difficult to prove, is 2.9 km/sec larger in all than the velocity of the Earth's motion, namely: 32.7 - 29.8 = 2.9 km/sec. The spacecraft should possess this excess velocity upon emergence from the Earth's sphere of activity. The required minimal initial velocity V_{req} is

$$V_{req} = \sqrt{V^2_{parabolic} + V^2_{excess}} = \sqrt{11.2^2 + 2.9^2} = 11.5 \text{ km/sec.}$$

It is desirable that at the instant of the spacecraft's launch, the Earth be situated at the parahelion of its orbit, where the velocity of our planet is 1 km/sec greater than at aphelion. /116

Since Venus is an inner planet, the spacecraft's emergence from the Earth's sphere of gravity should take place in a direction opposite to the motion of the Earth (Figure 26). Only under this condition will the spacecraft, leaving the Earth's sphere of activity, reach the sphere of solar attraction and begin moving under its influence along an elliptical trajectory, approaching the orbit of Venus. But this, of course, does not indicate that a spacecraft sent to Venus will always move in the reverse direction relative to the Sun. Its launch in the opposite direction is necessary to decrease the spacecraft's orbital velocity in comparison with the Earth's orbital velocity. The minimum necessary velocity in this case should be 27.2 km/sec, that is, less than the Earth's orbital velocity by 2.6 km/sec (29.8 - 27.2 = 2.6 km/sec). The initial velocity which it is necessary to impart to a spacecraft is

$$V_{initial} = \sqrt{11.2^2 + 2.6^2} = 11.4 \text{ km/sec.}$$

It is desirable that, at the instant of the spacecraft's launch, the Earth be situated at the aphelion of its orbit, where its velocity is a minimum.

Flight of a Spacecraft Along the Interplanetary Section /117

The velocity of a spacecraft flying outside the sphere of activity of the planet does not remain constant. As its distance from the Sun increases, the velocity decreases, and as its distance from the Sun decreases, its velocity increases. Thus for a flight to Mars, the spacecraft's orbital velocity decreases from 32.7 km/sec to 21.5 km/sec (Figure 27), but on the contrary, for a flight to Venus, it increases from 27.2 to 37.7 km/sec (Figure 28).

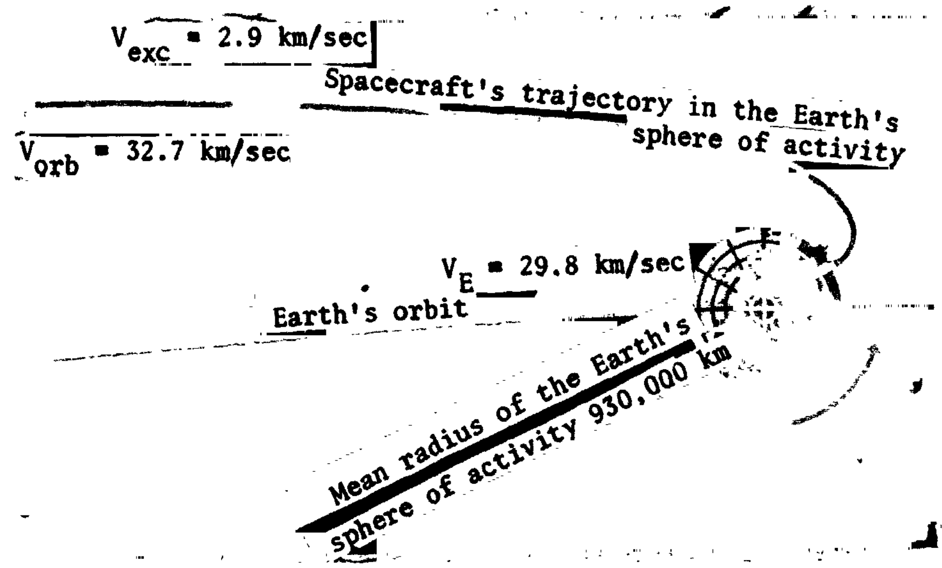

Figure 25. Schematic Diagram of the Initial Section of the Flight of a Spacecraft in the Earth's Sphere of Activity During a Flight to Mars.

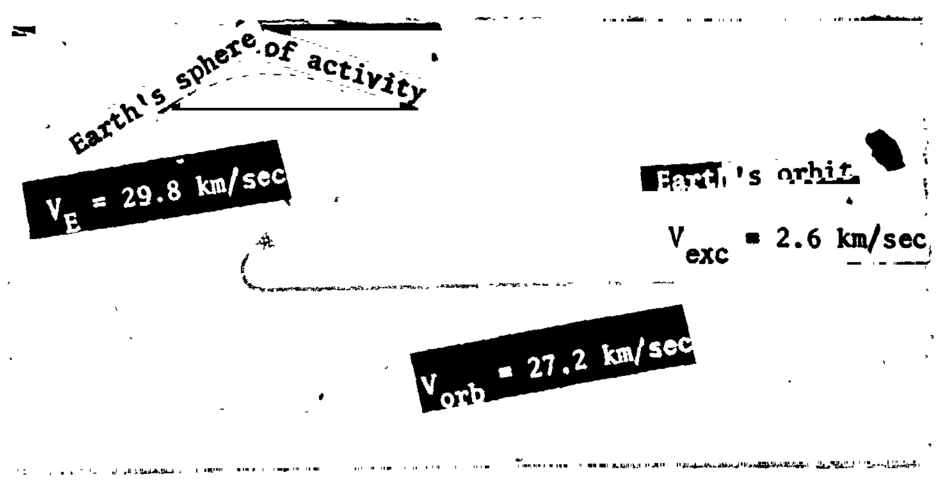

Figure 26. Schematic Diagram of the Initial Section of a Spacecraft's Flight in the Earth's Sphere of Activity for a Flight to Venus.

The velocity necessary for the flight of a spacecraft from the orbit of one planet to the orbit of another can be calculated from the equation

$$V_{orb} = V_{circ}\sqrt{\frac{2R_2}{R_1+R_2}},$$

where V_{circ} is the circular velocity at a distance R from the Sun, and R_1 and R_2 are the radii of the elliptical trajectory at perihelion and aphelion.

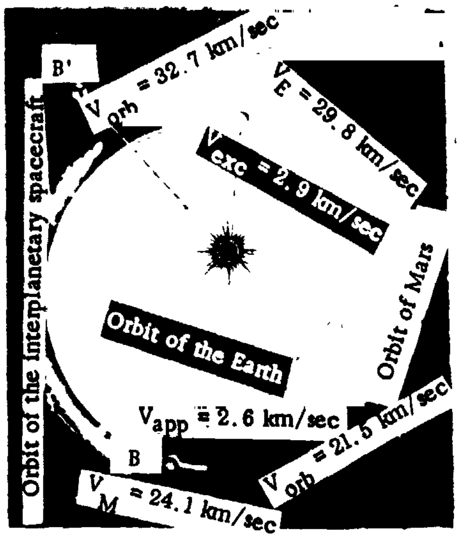

Figure 27. Schematic Diagram of the Interplanetary and Terminal Sections of a Spacecraft's Flight to Mars along an Energetically Optimum Trajectory: A, Position of the Earth in its Orbit at the Instant of the Spacecraft's Launch; B, Position of Mars in its Orbit at the Instant of the Spacecraft's Launch from Earth; A', Position of the Earth in its Orbit at the Instant of the Spacecraft's Approach to Mars; and B', Position of Mars in its Orbit at the Instant of the Spacecraft's Approach to it.

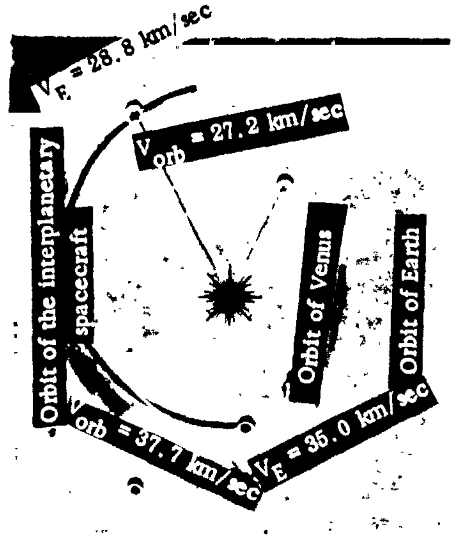

Figure 28. Schematic Diagram of the Interplanetary and Terminal Sections of the Flight of a Spacecraft to Venus along an Energetically Optimal Trajectory: A, Position of the Earth in its Orbit at the Instant of the Spacecraft's Launch; B, Position of Venus in its Orbit at the Instant of the Spacecraft's Launch from the Earth; A', Position of the Earth in its Orbit at the Instant of the Spacecraft's Approach to Venus; and B', Position of Venus in its Orbit at the Instant of the Spacecraft's Approach to It.

Using Kepler's laws, it is easy to find the spacecraft's time of flight along a semielliptical trajectory, knowing that the semimajor axis of this orbit is equal to one-half the sum of the semimajor axis of the Earth (one astronomical unit) and the semimajor axis of the destination planet's orbit. Having denoted its value in astronomical units by α, we derive the following equation for calculating the duration of a flight along a semi-elliptical trajectory:

$$T = 182.6\left(\frac{1+\alpha}{2}\right)^{3/2} \quad \text{(days)}.$$

Thus we find the time of a flight to Venus to be 146 days and to Mars — 259 days. If one takes into account the fact that the orbit of Mars (in contrast to the orbit of Venus) is an ellipse with a significant eccentricity, then depending on the position of Mars in its orbit, the flight time to it along a semi-elliptical trajectory can vary from 237 to 281 days. In this case it is necessary to understand by α one-half the diameter of the orbit at the rendevous point of Mars and the spacecraft. /118

Flight Along the Terminal Section of the Trajectory

Entering the destination planet's sphere of gravity, the spacecraft will begin to approach it with ever-increasing velocity. It is important to remark that if the spacecraft enters the planet's sphere of gravity with zero velocity, it will increase its own velocity to the escape velocity (for the given planet). But since the spacecraft's entry velocity into the destination planet's sphere of activity is always greater than zero, the velocity of its motion on its approach flight to the planet will be greater than the escape velocity.

It is shown above that in the case of the flight of a spacecraft along an energetically optimum trajectory it and the target planet move along different orbits and with different velocities. But since the heliocentric velocity of /119
the spacecraft's approach flight to Mars is equal to 21.5 km/sec (see Figure 27) and the orbital velocity of Mars around the Sun is 24.1 km/sec, then in the encounter Mars is moving more rapidly than the spacecraft by 24.1 - 21.5 = 2.6 km/sec. And this is because it approaches the Martian orbit along the tangent at the aphelion of its own trajectory. Therefore in order that a rendevous be accomplished, the spacecraft must so approach the Martian orbit that it appears in front of Mars. Having a greater velocity, Mars will catch up with the spacecraft, and it will seem to the cosmonauts, if they are onboard, that they are flying toward the planet.

In the case of an approach flight to Venus (Figure 28), the spacecraft's velocity will be 37.7 km/sec, since it will approach along the tangent at the perihelion of its own trajectory, and since Venus has an orbital velocity of 35.0 km/sec, the spacecraft will catch up with it, approaching at a speed of $V_{app} = 37.7 - 35 = 2.7$ km/sec.

For a spacecraft's rendevous with this or the other planet it will execute the following maneuvers:

- flyby over a specified region of the planet, which has already been carried out by Soviet and American spacecraft in flybys past Mars and Venus;

- placement into the orbit of an artificial satellite of the target planet (which has also been carried out by the Soviet spacecraft Mars-2 and Mars-3 and the American spacecraft Mariner-9);

- entry into the planet's atmosphere with subsequent aerodynamic acceleration (if the planet has a gaseous envelope) and a landing on it. The Mars-2 and Mars-3 spacecraft accomplish this maneuver for the first time; and

- flight around the planet with a landing on it or with a subsequent return to the Earth.

Interplanetary Trips to Mars

We already know what the minimum velocity is for a flight of a spacecraft away from the Earth so that it can fly to Mars along a semi-elliptical trajectory (Figure 29, trajectory 1) and what the duration of its flight is. If during the flight away from the Earth, the spacecraft receives a continually greater velocity, the time for the transfer flight will continually be shortened. In the case of an initial velocity of 11.8 km/sec (trajectory 2) the spacecraft reaches Mars in 165 days. If we add 0.2 km/sec more, the flight's duration is decreased by 21 days (trajectory 3). In the case of a velocity of 13 km/sec, the flight lasts 105 days (trajectory 4), and if the spacecraft moves with an initial velocity of 16.7 km/sec, i.e., with the third cosmic velocity (along a parabolic trajectory), it will reach the planet in 70 days. This is one of the most remarkable characteristics of interplanetary navigation: as the initial velocity increases in all by a factor of 1.4, the duration of a flight decreases by a factor of 3.7 in the given case. Why? Figure 29 gives a clear representation of this. This occurs due to a significant shift along the Martian orbit of the point of encounter of the spacecraft with Mars. A still greater increase in the velocity of its flight away from the Earth will lead to hyperbolic trajectories. However, such trajectories, although /121 they shorten the duration of the transfer flight, are uneconomical, since they do not compensate for the additional fuel expenditures necessary for the spacecraft to catch up in its flight with the destination planet and for deceleration of the spacecraft upon entering a near-planetary orbit. It is not difficult to see from Figure 29 that the time of launch is determined by the difference in the angular velocity of the Earth and Mars in their revolution around the Sun. Knowing the central angle (relative to the Sun) described by the spacecraft during the flight (angular distance of the flight), and taking into account the fact that Mars lags behind the Earth by 0.46° per day, one can determine the angles corresponding to the initial configuration. The angular distance between the directions to the planet and to the Earth (if one is looking from the direction of the Sun) at the instant of launch should be equal to the product of the flight time of the spacecraft by the difference in the angular velocities of the planet and the Earth. Only in this case will the spacecraft and the planet encounter each other in orbit at a specified point.

In the case of a flight along a semi-elliptical trajectory with a minimum fuel expenditure, the spacecraft's launch from Earth should be made when Mars, moving in its own orbit with a smaller angular velocity, appears 44° in front of the Earth. Under this condition the spacecraft will catch up to the planet Mars in 259 days. In order that it be able to catch Mars in 70 days, moving along trajectory 5, it should be launched at that instant when Mars is 35° in front of the Earth. Therefore for each flight trajectory there occurs a definite initial position of Mars (points 5, 4, 3, 2, 1) with respect to the Sun-Earth line[13] of the initial configuration of the Earth and Mars. But since any relative configuration of the Earth and the planet is repeated each synodic period, the time of a flight from Earth to Mars for a specified type of trajectory is repeated every 780 days — 2 years, 1 month, 20 days; therefore the use of any of the indicated trajectories is possible only during this period.

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[13]This line is assumed fixed in Figure 29 for simplicity. Actually a launch along trajectories 1, 2, 3, 4, 5 is accomplished from different points of the terrestrial orbit.

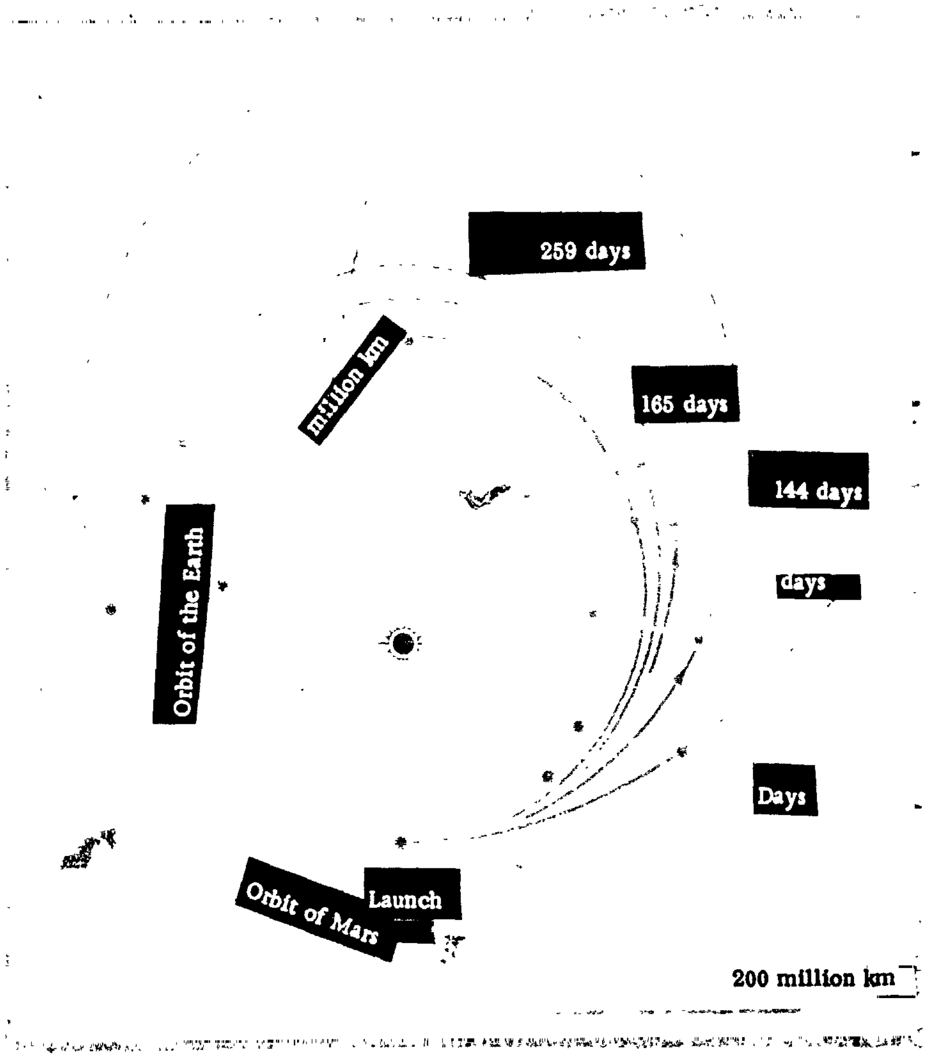

Figure 29. Trajectories of a Flight to Mars which are Tangent to the Earth's Orbit: I, II, III, IV and V, Trajectories of the Spacecraft's Motion. /120

The angles of the initial configurations for trajectories 1-5 differ by only 9°, which corresponds to a difference of 20 days. Therefore a flight to Mars during a synodic period along trajectories tangent to the Earth's orbit with an initial velocity in the range between the minimum and the third cosmic velocity is possible only during the most favorable period having a duration of 20 days. Using astronomical yearbooks, it is easy to find this favorable period. For Mars this configuration occurs 96 days prior to each opposition. As we see, the range of possible dates of the start of a flight is very small in comparison with the synodic period, even if the spacecraft's initial velocity is equal to the third cosmic velocity. But the semi-elliptical trajectory, although the most favorable in the sense of fuel economy, is nevertheless inconvenient in certain other respects. In particular, it requires an increased accuracy for the launch and results in the fact that at the instant of the spacecraft's encounter with the target planet they are both too far from the /122

Earth. That at the instant of the spacecraft's approach to Mars, its distance from the Earth to the approach point is equal to 239 million kilometers for trajectory 1. Therefore the trajectories actually selected differ from the semi--elliptical trajectory in the direction of some shortening of the flight time (to 220-230 days). Correspondingly, of course, the launch dates vary. As is well-known, launches of spacecraft to Mars have been carried out. In November of 1962 (the Soviet interplanetary spacecraft Mars-1), in November of 1964 (the American spacecrafts Mariner-3 and Mariner-4), in March of 1969 (the automatic spacecraft Mariner-6 and Mariner-7), and on May 19 and 28, 1971 (Mars-2 and Mars-3). On July 21 and 25 and on August 5 and 9, 1973 the launches of the Mars-4, -5, -6, and -7 spacecraft were carried out. In the near future favorable periods of flights to Mars will be: August-September of 1975, September-October of 1977, and October-November of 1979.

It follows from what has been said that the range of possible launch dates is expanded by the use of flight orbits different from the semi-elliptical trajectories. For flights of a spacecraft to a planet without return to the Earth, trajectories which provide a rapid flight are the most attractive. This is especially important in the case of flights to Mars and Venus, since the synodic periods of revolution of these planets relative to the Earth are very long.

Flights to Mars with Return to the Earth

We have discussed the flight of spacecraft to Mars without touching on the problems associated with their return. Automatic interplanetary spacecraft which fly past the planet, similar to what has been accomplished by the Soviet Mars-1 spacecraft and the American Mariner spacecraft, can be directed at Mars along these trajectories. These routes can be used for sending automatic spacecraft to Mars with the purpose of placing them into near-planetary orbit and also for landing them on the planet's surface like the Mars-2 and Mars-3 automatic spacecraft. However, in the case of flights both of automatic interplanetary spacecraft and manned spaceships to Mars with return to the Earth, it is necessary to calculate trajectories for the return flight. In fact not knowing the time which the entire flight will occupy, it is impossible to calculate the spacecraft's launch weight.

Out of the enormous range of flight trajectories of a spacecraft bound for Mars with its return to Earth, we will first discuss a flight along a semi--elliptical trajectory, which requires the minimum energy expenditure (Figure 30). Having been launched from the Earth, the spacecraft will carry out a landing on Mars in 259 days. During this time interval the Earth will shift along its own orbit by a significant distance, having described an arc of 259°. It is completely understandable that if the spacecraft is immediately directed back from Mars to the Earth, then in 259 days it, having arrived at the Earth's orbit, will not encounter the Earth, since in this time it will still describe an arc of 259° and will be located now at another point of its orbit. So that, having returned to the Earth, the spacecraft can rendevous with it, /123
it must spend 450 days on Mars or in a near-Martian orbit. Thus a round-trip flight with a stay on Mars will take 968 days.

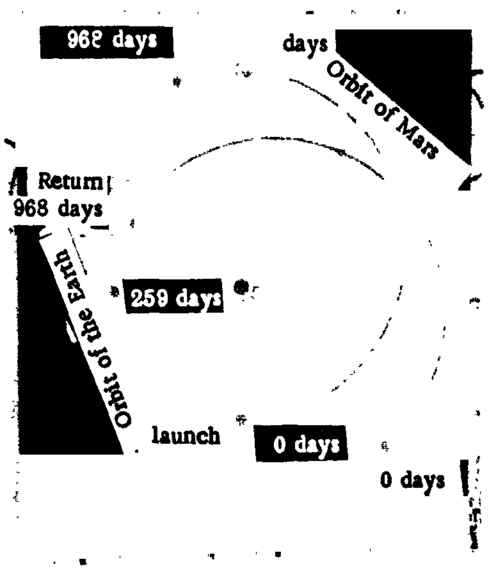

Figure 30. Earth-Mars-Earth Expedition (Duration is 259 + 450 + 259 = 968 Days).

In order to clarify this, we will carry out elementary calculations. Since the mean distance from Mars to the Sun is equal to 1.524 A.U., the length of the semi-major axis of the transition ellipse $\frac{1}{2}$ (1.524 + 1) = 1.262 A.U., whereby the duration of a flight from Earth to Mars is

$$T = \frac{1}{2} (1.262)^{3/2} = 0.71 \text{ year} = 259 \text{ days.} \qquad (7)$$

The average orbital angular motion of the Earth can be determined using the following relationship:

$$\frac{360}{365.25} = 0.9856 \text{ degrees per day (deg/day)},$$

but for Mars it is equal to 0.524 degs/day. Thus in 259 days Mars will have shifted along its orbit by approximately 136°. Therefore in order that the spacecraft be able to encounter Mars, the instant of its launch must lag Mars by 180° - 136° = 44°. Since the Earth "catches up with" Mars at an angular velocity of 0.986 - 0.524 = 0.462 degs/day, the spacecraft should be launched $\frac{44}{0.462}$ = 96 days prior to the opposition of Earth and Mars, i.e., 95° behind, with respect to the Earth's angular position, of the opposition point. During the spacecraft's flight the Earth will shift by 256° and by the moment of the encounter will lag Mars by 76°. Above we showed that, as regards the spacecraft's stay on Mars, it should remain on it 450 days in anticipation of a return flight. Why? To illustrate the return path, let us alter the direction of motion to the opposite way. This will indicate that now Mars should lag the Earth by 76°. But such conditions will occur again only in 450 days. Thus the total duration of a flight from Earth to Mars and back amounts to 259 + 450 + 259 = = 968 days.

In Table 5 data are given for the flight of a spacecraft to Mars and back for the period 1973-1980. /124

If the flight to Mars takes place along a parabolic trajectory, when the first branch corresponds to the outward flight at the third cosmic velocity and the other branch represents the mirror image of this arc of the parabola traversed in the reverse direction, the time of stay on Mars can be shortened to 12 days (Figure 31).

TABLE 5.

Dates of launch from Earth and duration of flight to Mars along a semi-elliptical trajectory.

Launch date	Flight duration, days	Date of arrival from Mars
August 4, 1973	281	May 12, 1974
September 10, 1975	281	June 17, 1976
October 11, 1977	275	July 13, 1978
November 9, 1979	262	July 28, 1980

Dates of departure from Mars and duration of flight to Earth

Launch date	Flight duration, days	Date of arrival at Earth
May 3, 1973	240	January 1, 1974
July 8, 1975	239	March 1, 1976
August 9, 1977	252	May 7, 1978
September 7, 1979	267	January 4, 1980

Some information is given in Table 6 about orbits in the case of the flight of a spacecraft along the route Earth-Mars-Earth following a semi-ellipse tangent to both orbits (this version was discussed above) and along a segment of a parabola tangent to the orbit of the Earth and tangent to the orbit of Mars.

TABLE 6.

Data about orbits	Shape of the trajectory	
	Semi-ellipse	Segment of a parabola
Initial velocity, km/sec	11.59	16.66
Duration of the flight to Mars, days.....	259	70 2
Time of stay in orbit as a satellite of Mars or on its surface, days	450	12
Velocity of takeoff from surface of Mars, km/sec..........................	5.69	20.7
Duration of flight to Earth, days........	259	70
Velocity of atmospheric re-entry, km/sec................................	11.2	20.7
Total duration of flight, days..........	968	152

Analyzing this table, it is not difficult to see that the parabolic trajectory permits not only shortening by almost a factor of 4 the length of the flight in comparison with the flight along the semi-ellipse but de- /125
creasing (by a factor of 35!) the time of stay on Mars. However, this is achieved at the expense of a significant increase in the takeoff velocity from Earth and from Mars and also in the landing speed on Earth which it is necessary to cancel out by deceleration, a maneuver which requires a large fuel supply.

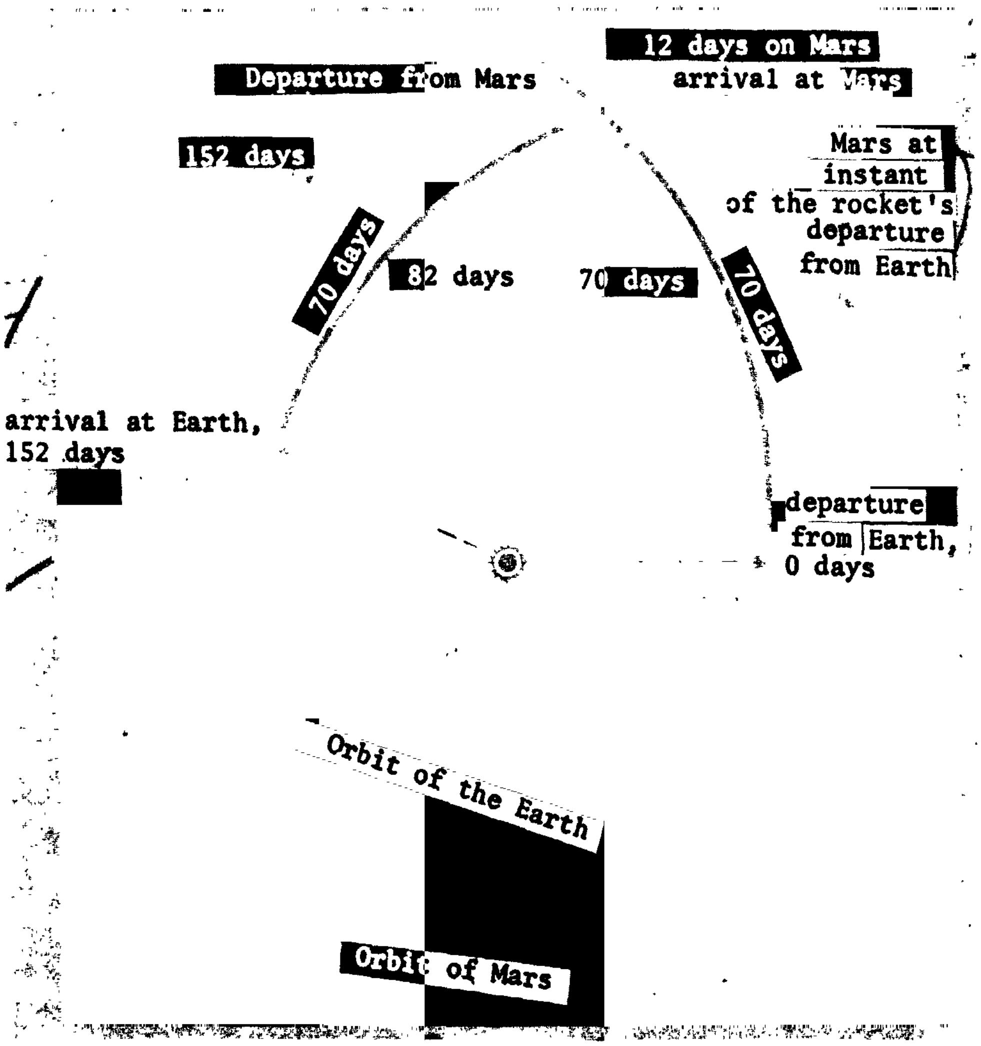

Figure 31. Flight Trajectory of an Interplanetary Spaceship Along Segments of a Parabola Tangent to the Orbit of the Earth and Intersecting the Orbit of Mars.

Since a flight to Mars along the optimum (from the point of view of energy expenditures) trajectory requires a lengthy stay of the spacecraft in the neighborhood of Mars or on its surface, but the flight along parabolic trajectories, although it shortens greatly this time, nevertheless results in a significant increase in the takeoff and landing velocities at the planets, the task naturally confronted the investigators seeking other methods which permit shortening the duration of an interplanetary journey with acceptable energy expenditures. /126

It was found that the holdover period on Mars (i.e., the spacecraft's time of stay on it or near it) can be decreased by means of altering the profile of the flight orbits in the following way: the flight from Earth to Mars is carried out over a short trajectory, and conversely the spacecraft returns along a long path or vice versa. Some computation of data of such flights are given in Figure 32 and Table 7.

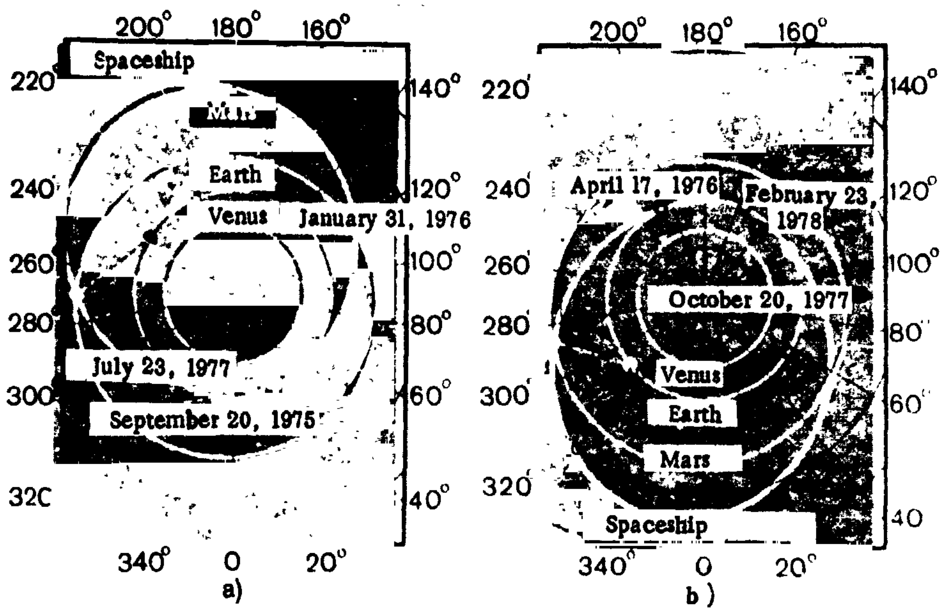

Figure 32. Projection of the Trajectories Onto the Ecliptic Plane: a, Short-Long Trajectory (Launch on December 20, 1975); b, Long-Short Trajectory (Launch on April 17, 1976).

TABLE 7. A COMPARISON OF THE TRAJECTORIES' PARAMETERS.

Type of Trajectory	Short-Long	Long-Short
Date of launch from Earth	September 20, 1975	April 17, 1976
Velocity increment upon launch from artificial Earth satellite orbit, m/sec	4,620	4,280
Inclination of the asymptote of the outward flight's hyperbolic trajectory, degrees	33.31	30.24
Flight time from Earth to Mars, days	133.29	582.21
Return time, days	538.64	98.73
Stay time in Mars' sphere of activity, hours	37.74	29.92
Altitude of pericenter of the flight trajectory, km	196.48	208.66
Location of the pericenter relative to Mars	in the northern hemisphere	in the southern hemisphere
Inclination to the plane of Mars' equator, degrees	144.21	13.10

Type of Trajectory	Short-Long	Long-Short
Conditions of illumination at pericenter	Night	Day
Return velocity to Earth, m/sec	14,600	15,640
Date of landing on the Earth	July 23, 1977	February 28, 1978

As we see, although the duration of the interplanetary trip is shortened under these conditions (insignificantly, it is true, with respect to a flight along the optimum symmetric trajectories), nevertheless the spacecraft's approach velocity to the Earth remains very large as before.

This is especially noticeable for many "unfavorable years" when the eccentricity of Mars' orbit results in excessively large terminal velocities of the spacecraft's approach to the Earth corresponding to from 15 to 23 km/sec, depending on the flight's year. The following question confronted scientists in a completely natural way: how to decrease it? At first it was suggested either to achieve this by deceleration using rocket motors upon the spacecraft's approach to Earth or to enter into the atmosphere's dense layers at a high speed and diminish by means of aerodynamic breaking the flight's velocity. However, the first method requires such an increase in the spacecraft's initial weight that its flight practically becomes impracticable, and the other method subjects the crew to excessive overloads and requires the creation of a descent craft designed for such a high velocity. Subsequent investigations have shown that it is by far more economical from the point of view of energy expenditure if, during a flight from Mars to Earth, one applies a maneuver with deceleration near perihelion, the so-called perihelion deceleration maneuver, along the spacecraft's flight trajectory (Figure 33). Calculations show that, because of the perihelion deceleration maneuver, the velocity of the spacecraft's entry into the Earth's atmosphere is decreased its return from Mars from the value indicated in Figure 34 by the white columns to the values indicated by the shaded columns. As is evident, the velocity after the maneuver is significantly less than the velocity attained by means of applying the deceleration maneuver upon approach to the Earth for the same decrease in entry velocity. It is possible to achieve a significant reduction in the spacecraft's initial weight if, prior to the start of the perihelion deceleration maneuver, it is freed of the entire mass of the useful load already unnecessary for the remaining 60-90 days of the flight to the Earth. Along with this another still more economical method of deceleration has been suggested. It consisted of the use by the spacecraft returning from Mars to the Earth of the gravitational field of the planet Venus. This method permits decreasing the approach velocity to the Earth to 12-13 km/sec at the expense of a small fuel expenditure or without any expenditure. Thus the use of Venus' gravitational field permits accomplishing flights to Mars during the unfavorable periods.

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/128

For comparison the characteristics of a rapid direct Earth-Mars-Earth flight with placement into orbit as a Martian satellite and the characteristics of an Earth-Mars-Venus-Earth flight with placement into the same orbit of Mars (the duration of the stay in Mars' orbit is 30 days) with the spacecraft's launch during one of the unfavorable periods, are given in Table 8.

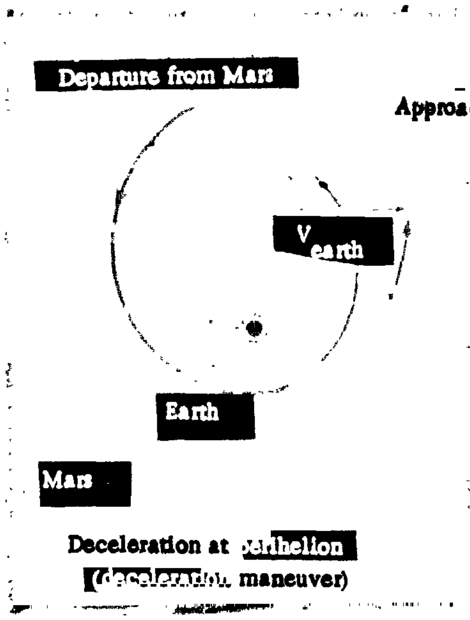

Figure 33. Maneuver with Deceleration at Perihelion of the Spacecraft's Motion Trajectory and its Effect on the Approach Velocity to the Earth.

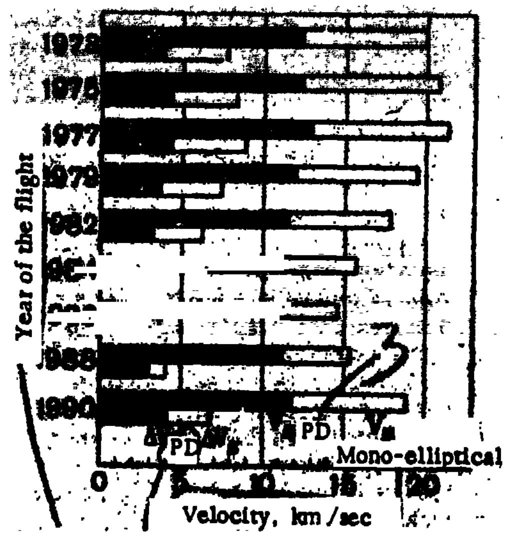

Figure 34. Decrease in the Entry Velocity into the Earth's Atmosphere V_E in the Case of an Optimal Elliptical Trajectory in a Maneuver with Deceleration at Perihelion. A comparison of the velocity changes produced by deceleration at perihelion (ΔV_{PD}) and upon approach to the Earth (ΔV_E).

TABLE 8. /129

Characteristics of the Flight	Direct Flight	Flight with Flight Around Venus
Duration of the flight, days	450	530
Velocity impulse of acceleration away from the Earth, km/sec	4.61	4.03
Velocity impulse of deceleration at Mars, km/sec	3.31	2.26
Velocity impulse of acceleration at Mars, km/sec	4.13	2.9
Velocity impulse at Venus, km/sec	--	0.08
Total energy expenditures, km/sec	12.05	9.27
Altitude of flyby above Venus, km	--	6,000
Entry velocity into Earth's atmosphere, km/sec	15.5	13.4

The new method of interplanetary navigation discussed by us indicates that, if a favorable navigational season for flights between A and B does not exist, then it may occur between A and C and then C and B. But its advantages consist not only of this. Interplanetary flights to Mars with a flyby near Venus /130 become advantageous even during favorable navigational periods. Turn your attention to Table 9. The basic characteristics of an Earth-Mars-Earth flight with placement into orbit as a Martian satellite and an Earth-Mars-Venus-Earth with placement into the same orbit during a more favorable navigational period are given in this table.

TABLE 9.

Flight	Direct Earth-Mars--Earth Flight	Flight with Placement into Orbit as Martian Satellite and Flyby Past Venus
Takeoff from Earth	March 20, 1984	January 2, 1982
Departure velocity from Earth's gravitational field, km/sec	4.3	3.81
Flight time in outer space, days	220 (Earth-Mars)	200 (Earth-Mars)
Entry maneuver into Mars' gravitational field, km/sec	3.05	4.27
Arrival at Mars	October 27, 1984	July 21, 1982
Stay time in orbit as Martian satellite, days	529	69
Takeoff from Mars	April 9, 1986	September 28, 1982
Maneuver for leaving the gravitational field of Mars, km/sec	2.74	4.27
Flight time at return to Earth, days	176 (Mars-Earth)	149 (Mars-Venus) 161 (Venus-Mars)
Arrival at Earth	October 2, 1986	August 4, 1983
Entry velocity into the Earth's atmosphere, km/sec	Maneuver of placement into artificial Earth satellite orbit, 3.26 km/sec	11.9
Total flight time, days	925	579
Total flight velocity without taking into account special maneuvers at the target planet, km/sec	7.35	12.35

Note: All the velocity impulses, with the exception of those which are required to accomplish the maneuver associated with the interruption of heliocentric flight, must be multiplied by a factor of 1.04 to take losses into account.

Analyzing the data cited in the table, one can conclude that a flight to Mars with a flyby past Venus possesses a significant advantage over the direct flight. This method of interplanetary navigation extends by far our possibilities in the pace of investigating outer space and celestial bodies with acceptable energy expenditures.

The most favorable periods for flight to Mars will be 1973 and 1975. After 1975 Mars will pull away from the Earth by a significant distance, and the Sun's activity will increase at this time. Therefore not only more powerful booster rockets will be required for a flight, but also massive protective shields will be necessary for manned spaceships. An extremely realistic period for flight to Mars by an expedition of investigators is 1975. If in this year such a flight does not occur, then it is necessary to wait for a more favorable period, which will begin in 1982. During the period from October of 1981 through June of 1988 there will be ten "windows" for a flight to Mars, each with a duration of about a month. In 1990 the number of "windows" during the opposition period decreases significantly, but in return flights during conjunction periods will become possible.

Some distinctive features of flights during a period of opposition, a period of conjunction, and with the use of a gravitational field are indicated in Table 10 cited below.

TABLE 10.

Type of Flight	Velocity increment required for transition from a geocentric orbit to a trajectory to Mars, km/sec	Velocity increment required for launch from Mars, km/sec	Entry velocity into Earth's atmosphere, km/sec	Duration of stay on Mars in days	Total flight duration in Earth days
During a period of opposition	4.57	5.03	20.1	10	430
During a period of conjunction	4.27	2.59	11.9	480	920
With the use of Venus's attractive force	4.27	5.03	13.4	10	490

We have also written that at the end of 1971 Mars was visited by three artificial satellites of the Earth: two Soviet and one American. The descent stage of the Mars-3 automatic spacecraft first accomplished a soft landing on the Martian surface and transmitted radio signals from there. /131

As information about the parameters of Mar's atmosphere accumulates and the complete picture of the Martian relief is clarified, it will be necessary to deliver to the planet an automatic station with a lengthy lifetime. An exceedingly attractive idea is the placement on Mars of self-propelled devices which, similar to the Lunokhods, will be able to investigate in detail the orange planet. However, very complicated problems associated with the motion of a Marsokhod arise. The main difficulty is control from the Earth – the long time interval between the sending of a radio signal from Earth to its reception onboard the Marsokhod and the journey of a reply radio signal to the Earth – from 70 to 40 minutes, depending on the distance between Mars and Earth. In fact time to process the information and accept solutions is necessary: to stop the device, to turn it in the desired direction, or to take an interesting sample onboard. Therefore the necessity arises of devising a system of automatic navigation which would be able independently to select a path of motion acceptable from the point of view both of avoiding obstacles and for carrying out scientific investigations.

Interplanetary Trips to Venus

First let us consider two extreme cases of an interplanetary route – the shortest and the longest. It would seem at first glance that the most suitable trip is the direct one connecting the nearest points of the orbits of Earth and Venus. In fact in this case the flight duration is the shortest (Figure 35). For this it is necessary as has been stated above, to launch the spacecraft in a direction opposite to the Earth's motion. Then it, "having extinguished" the heliocentric velocity (and it is large – 29.8 km/sec), lags for an instant at the boundary of the Earth's sphere of gravity and then begins moving along at complex curve in the direction of Venus' orbit, gradually approaching it. In order to stop its "falling" into the Sun along the shortest path, i.e., along a straight line, it is necessary to impart to the spacecraft a velocity of not less than 31.8 km/sec at the moment when it, having completely overcome the Earth's attraction, begins to move now along a straight line in the direction of the Sun. It is determined from the equation

$$V_{total} = \sqrt{11.2^2 + 29.8^2} = 31.8 \text{ km/sec}. \quad (8)$$

Leaving the Earth's sphere of gravity and having been acted on by the influence of the Sun's powerful attraction, the spacecraft, "falling" towards the Sun along a straight line, will intersect Venus' orbit in 64 days, having flown 41,000,000 kilometers. It is possible to provide for the spacecraft's encounter with the destination planet in the case of a specified choice of launch time. However, at the present level of technology, it does not appear possible to impart such a large velocity to a spacecraft having a con- /132 siderable weight. In addition to this, the method of flight which we have discussed has one more very significant insufficiency: a spacecraft, "falling" towards the Sun, will continually increase its velocity and, intersecting Venus' orbit, receive a velocity of 26.1 km/sec. This velocity is determined from the equation:

$$V = \sqrt{2(35^2 - 29{,}8^2)} = 26{,}1 \text{ km/sec}. \quad (9)$$

But since, at the instant of encounter, the velocity vectors of the spacecraft and the planet are directed mutually perpendicularly, we obtain from the parallelogram rule an encounter velocity of 43.6 km/sec, which is determined from the following equation:

$$V_{encounter} = \sqrt{34^2 + 26^2} = 43.6 \text{ km/sec.} \qquad (10)$$

If we take into account the fact that Venus' attraction will also make a small addition, then the total velocity will be of the order of 44 km/sec. It is completely understandable that, in order to cancel this velocity, it would be necessary to have on the spacecraft very powerful rocket motors and a considerable fuel supply. Thus a flight to Venus along a straight-line trajectory, regardless of its shortness in time and its apparent simplicity, is actually very uneconomical, and therefore it is unsuitable for practical implementation.

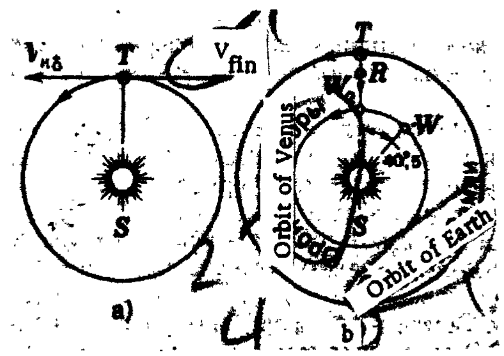

Figure 35. Flight to Venus along the Shortest Path: a, "Quenching" the Earth's Heliocentric Velocity. S, Sun; T, Earth; $V_{k\delta}$, heliocentric velocity of the Earth. V_{fin}, velocity of the rocket upon emergence from the Earth's sphere of activity. b, Rocket's falling into the Sun and its encounter with Venus in the case of a flight along a straight line. S, Sun; T, Earth at the instant of the rocket's launch, W_1, Venus at the instant of the rocket's launch, W_2, Venus at the instant of encounter with the rocket and R, rocket along a straight line trajectory to Venus.

The most acceptable with respect to energy would be a flight along a trajectory which is the arc of an ellipse tangent to the orbits of Earth and Venus at points opposite from the Sun.

But a flight along such a trajectory, being acceptable energetically, has, of course, its own inadequacies. According to Kepler's third law, the semi-major axes of the elliptical orbits and the revolution periods of the Earth and the spacecraft around the Sun are connected by the relationship:

$$\frac{T_{SC}^2}{T_{Earth}^2} = \frac{a_{SC}^3}{a_{Earth}^3},$$

from which

$$T_{SC} = T_{Earth}\left(\frac{a_{SC}}{a_{Earth}}\right)^{3/2}. \qquad (11)$$

Substituting numerical values into this equation, we obtain /133

T_{SC} = [redacted] days

But since, on a trip to Venus, the spacecraft will fly only one-half of an ellipse, the duration of its flight amounts to approximately 146 days. For such a flight is it necessary to give spacecraft a specified flight plan in which it, having overcome the Earth's attraction and moving along the proper orbit under the influence of the Sun's attraction, could encounter the destination planet. However, due to the difference in the revolution periods of the planets around the Sun the mutual position of the Earth and Venus is continually changing. Therefore a flight to Venus with minimum speed is possible only at rigorously specified periods of the mutual arrangement of the planets. Such periods are repeated once every one year seven months and ten days, i.e., every 584 days. Small deviations of up to 2 weeks in either direction from the most suitable (optimum) time are permissible, since the duration of the suitable period is about a month.

Upon the spacecraft is put into a trajectory, it should have not only the specified velocity at the boundary of the Earth's sphere of influence but a carefully calculated velocity vector direction. And since the tangential orbit is very sensitive to all deviations from the calculated initial conditions, a negligible error in the velocity upon entry into orbit on the order of 1 m/sec results in the spacecraft's deviating from the "target" point near Venus by almost 70,000 km. Therefore in practice a version of the trajectory is usually selected which lies between the two extreme cases under discussion. The trajectories along which the flights of the automatic interplanetary stations (AIS) to Venus are presently traversing correspond to them. A flight along such a trajectory lasts 3-4 months, and the distance between the Earth and Venus varies within the limits of 70-80 million kilometers. However, as has already been stated above, it is necessary in carrying out such flights to maintain scrupulously the launch date. In connection with this, the selected optimum trajectory cannot be realized at any instant of time at all.

As the calculations show, the flights must be made with the condition that the Earth "lead" Venus in angular motion about the Sun by 54° at the instant of launch. Since the time of such a mutual arrangement is well known, it is possible to formulate an exact description of the spacecraft's launch to Venus, taking into account the fact that such a mutual configuration is repeated, as has already been stated above, every 584 days. The favorable seasons in the upcoming years are: October-November of 1973, May-June of 1975, January of 1977, August of 1978, and March-April of 1980. Each season lasts approximately 2 weeks, i.e., shorter than the "launch windows" to Mars, since Venus catches up more rapidly with the Earth in its angular motion around the Sun than the Earth catches up with Mars. The most favorable (due to the nearness to the line of nodes) are the June and December seasons (the latter occur in the coming decade). In Table 11 below data are given for a flight from the Earth to Venus and back again along a semi-elliptical trajectory. /134

Earth-Venus-Interplanetary Trajectory

It was shown above that in the case of minimum fuel expenditure, the duration of a flight from Earth to Venus and back again is 758 days. This period is stipulated by the following considerations: the flight from the Earth to Venus takes

longer than 46 days, and a lifetime is expended for the return trip. In order to return to the Earth along a similar semi-elliptical trajectory, it is necessary to spend 466 days on or near Venus. But is it possible to shorten the duration of an expedition to Venus? Undoubtedly it is possible, but in order to do this it is necessary, as has already been stated above, to increase the departure velocity of the interplanetary ship from the Earth. It is true that as the launch velocity increases up to 12.8 km/sec, the time of stay on Venus not only is not decreased but, quite contrary, is increased and reaches 584 days. But if one continues to increase the launch velocity, a remarkable result is obtained: the time of stay is shortened to a minimum. There is even such a path from Earth to Venus for which the spacecraft's return is possible immediately after its descent onto the planet. As a calculation has shown, such an /135
accelerated interplanetary flight is possible if the spaceship makes a landing on Venus at the same time as the planet and the Earth are situated in a single straight line with the Sun (or near this position). Under these conditions a flight from the Earth to Venus and back again would last less than 5 months, and the duration of the entire expedition to Venus would be shortened by approximately a factor of 5.

TABLE 11. DATE OF LAUNCH FROM EARTH, ARRIVAL AT VENUS, AND DURATION OF THE FLIGHT

Launch date	Duration of flight, days	Arrival date
October 24, 1973	145	March 18, 1974
June 4, 1975	148	November 30, 1975
January 10, 1977	145	June 4, 1977
August 8, 1978	147	January 2, 1979
March 23, 1980	146	August 16, 1980

DATES OF LAUNCH FROM VENUS, ARRIVAL AT THE EARTH, AND DURATION OF THE FLIGHT

Launch date	Duration of flight, days	Arrival date at Earth
November 3, 1973	147	April 5, 1974
June 9, 1975	144	November 7, 1975
February 1, 1977	147	July 3, 1977
September 9, 1978	144	February 3, 1979
April 2, 1980	146	September 5, 1980

Flights to the Outer Planets

A distinguishing characteristic of flights to the outer planets is of the fact that they would last not months, but years and decades. Thus in the case of minimum energy expenditures, a direct flight to Jupiter would take about 3 years, to Saturn — 6 years, Uranus — 16 years, Neptune — 30 years, and Pluto — on the order of 45 years (Figure 36).

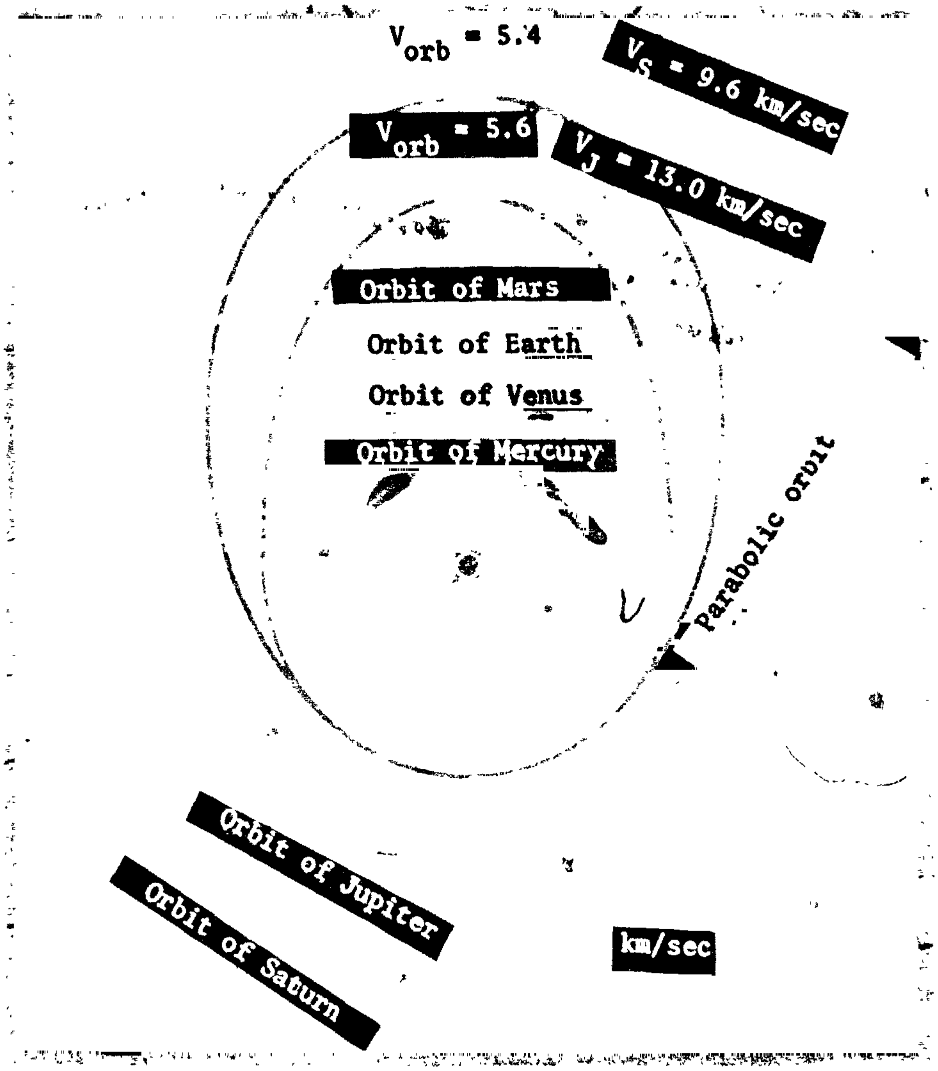

Figure 36. Elliptical Orbits of Interplanetary Spacecraft Flying to Jupiter and Saturn, and the Parabolic Orbit of a Galactic Probe Flying Beyond the Limits of the Solar System.

Great are the difficulties which face the designers of the rocket-space complexes for the investigation of these planets. The high velocities required in acceleration sharply decrease the useful payload weight of the spacecraft. The great distance from the Sun makes solar sources of electrical energy of little help. The mysterious asteroid belt threatens accidents. The extensive length of the flight places exceedingly high requirements on the flexibility and reliability of the onboard systems. However, the potential value of the scientific information obtained justifies all of the expenditures. In fact the giant planets and their families of satellites are the most interesting objects of the solar system. Investigations of them open slightly for us the curtain in front of the solar system's origin, since the satellite systems of Jupiter, Saturn, and Uranus are very similar to our planetary system and the discovery of the secret of their formation would facilitate the solution of such a fundamental problem of nature as the problem of the origin of the solar system.

The positions of the giant planets during the period from 1970 to 2000 are shown in Figures 37 and 38.

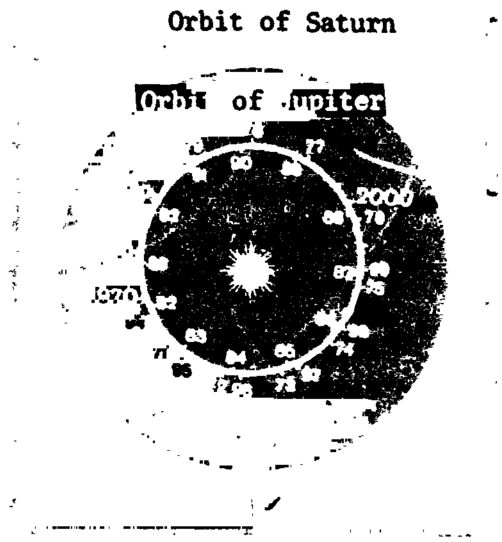

Figure 37. Positions of Jupiter and Saturn in 1970-2000. The positions refer to the start of the indicated year (the first day of January).

The synodic period of Jupiter's revolution is 399 days. Therefore the season suitable for flight to Jupiter occurs each year with a delay of one month. The most favorable periods are those which occur at the beginning of January and the beginning of June, when the Earth is situated along the line of nodes of Jupiter's orbit. The January periods are especially attractive since at this time the Earth is near its perihelion, where its velocity, as has already been stated, is greater by 1 km/sec than at aphelion, which is passed in June. Launches during the January seasons provide an angle of flight close to 186°, a minimum inclination of the flight plane to the plane of the ecliptic, and, of course, a minimum initial velocity.

The synodic period of Saturn is somewhat longer than a year. The season favorable for flight to Saturn occurs annually with a delay of 13 days. Concerning Uranus, Neptune, and Pluto, the delay amounts to 5, 2 and 1 day, respectively. /136

The synodic period of Mercury is 116 days (less than 4 months). The duration of a favorable phase, which occurs 3 times a year, is up to one week. The most favorable seasons are in the beginning of November and the beginning of May. In the course of a year, one of the favorable periods would be one of these. /137

However, Mercury is still unattainable for the rocket systems existing now in the case of a direct flight from Earth. But the possibility of "jumping over" to Mercury utilizing the gravitational field of Venus is attractive. If during a flight to Venus, the spacecraft is sufficiently close to an exactly selected altitude at an exactly calculated instant of time, Venus' gravitational field will turn it into a flight trajectory bound for Mercury. Such a maneuver is feasible only in 1973, and then it appears impossible right up until the 1980s. Therefore American scientists are planning to launch in 1973 a "Mercury" spacecraft to investigate the planet from a flyby trajectory. The implementation of such a flight is conceived in two stages. The spacecraft first approaches Venus at a distance of 4,000-6,700 kilometers from its surface, and then it is directed to Mercury. In the case of a flyby past Venus, two goals are pursued: in the first place, to carry out a probe of Venus' atmosphere and, in the second place, the spacecraft will obtain a velocity increment to its motion under the influence of Venus' attraction and will be able to fly around Mercury at a distance of approximately 3,000 km. It will photograph the planet's surface, determine its thermal characteristics, and carry out investigations of its atmosphere, magnetic field, and radiation belt. Scientists consider it advisable to install on this spacecraft a special detachable probe which will be ejected onto the surface of the planet being investigated.

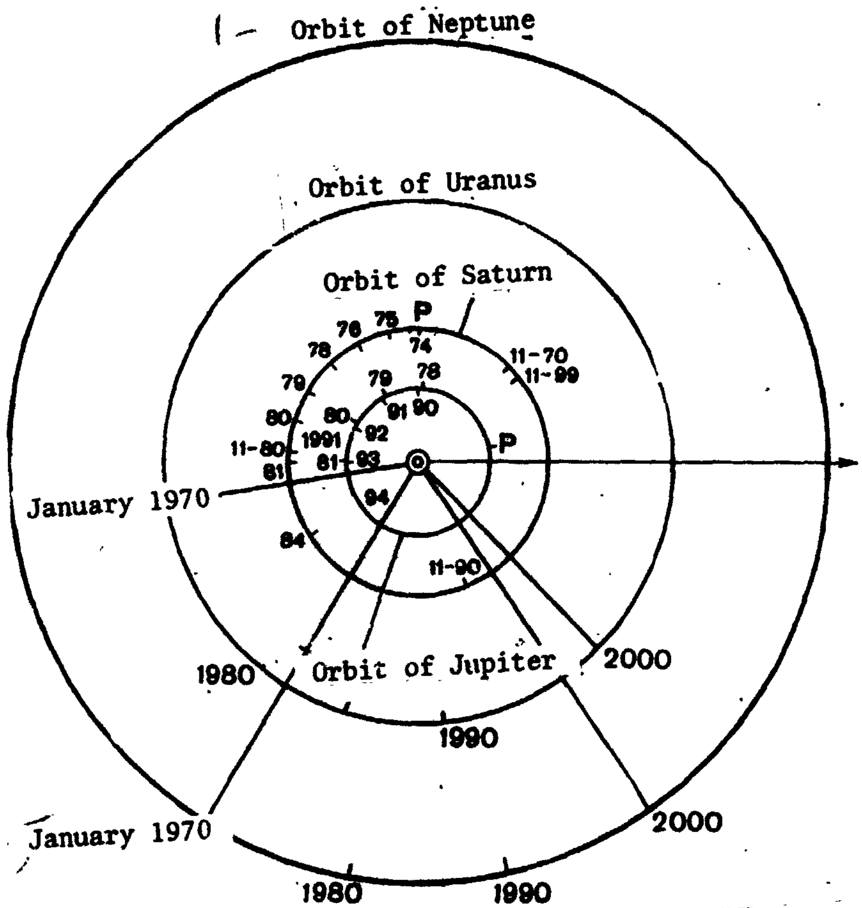

Figure 38. Positions of the Giant Planets in 1970-2000. The positions refer to the beginning of the indicated year (the first day of January).

In order to shortern not only the flight's duration but the energy expenditure, the use of the gravitational fields of such planets as the giant of the solar system — Jupiter and his younger brothers, Saturn, Uranus and Neptune — holds great promise. Imagine that the spacecraft is approaching Jupiter. The powerful gravitational field will accelerate the spacecraft to an enormous velocity. Rushing past this gigantic half-planet — half-star, it will begin to recede from it with a gradually decreasing velocity relative to Jupiter (Figure 39). If the spacecraft has a rocket motor, then even with a small fuel expenditure it is possible to accelerate it to hyperbolic velocity. Such an acceleration will make it possible (with the proper arrangement of the planets) to aim for other more distant planets. Each of these massive planets will fulfill the role of being its accelerator when the spacecraft flies past, and due to this, the flight will continue without expenditures of onboard energy or with a minimum energy expenditure. /138

It has been established by investigations that such an interplanetary tour becomes completely possible at the end of the 1970s. Favorable periods for the launch of a spacecraft are 1977, 1978, 1979, and 1980.

During these years the mutual arrangement of the planets will be suitable /139
for a single interplanetary spacecraft to fly by several planets successively, using their attraction for the so-called perturbation maneuver, which not only directs the spacecraft to the next planet, requiring almost no fuel expenditure, but shortens the flight's duration.

If such a favorable arrangement of the planets is not used, the next /140
such interplanetary journey simultaneously to several distant planets will have to wait until the year 2134.

In comparison with the optimum direct flights to the distant planets a flight utilizing Jupiter's gravitational field in place of a single or several large energy expenditures will result in a significant decrease in the duration of the journey (see Table 12).

TABLE 12.

Destination planet	Energy expenditures, km/sec			Flight duration, years		
	Optimum direct flight	Accel-erated direct flight	Flight past Jupiter	Optimum direct flight	Accel-erated direct flight	Flight past Jupiter
Saturn	7.28	8.5	7.5	6.1	2.88	2.88
Uranus	7.98	9.9	7.9	16.0	5.04	5.04
Neptune	8.28	10.2	8.2	30.7	7.56	7.56
Pluto	8.36	13.5	9.0	45.7	8.93	8.93

It is evident from this table that, by comparison with accelerated direct flight to distant planets, a flight "past Jupiter" will result, even in a case of identical duration, in significant decrease in energy expenditure. After the spacecraft flies by Jupiter, it is possible to return it to Earth, directed towards the Sun, push it out of the ecliptic plane at an angle of 96°, and direct it beyond the limits of the Solar System.

In this respect a version of the flight becomes especially interesting during which a turning of the trajectory should occur in the gravitational field of Jupiter, Saturn, and Uranus with the effect of providing a consecutive flyby past the planets. A favorable arrangement of the planets will permit the spacecraft, after launch from Earth, for example, on September 4, 1977, to complete a flyby past Jupiter on January 29, 1979, and past Saturn on September 3, 1980; it will sweep by not far from Uranus on February 1, 1984, and it will approach Neptune on November 8, 1986 (see Figure 35 b), i.e., in 9.2 years after launch from a near-Earth cosmodrome. It is planned that the spacecraft will fly past beneath the rings of Saturn. If a trajectory were to be selected along which the spacecraft's motion would carry it above the rings of Saturn, which is more dangerous, the flight's duration would increase somewhat, and the spacecraft would complete its flyby past Neptue 11.6 years after launch. The energy expenditures for the first version amount to 7.6 km/sec and for the second – 6.8 km/sec.

Some computational data for such a flight are given in Table 13.

TABLE 13.

	Above the rings	Below the rings
Launch date from Earth	September 1, 1977	September 4, 1977
Launch velocity from Earth	14.6 km/sec	15.4 km/sec
Flight time to Jupiter	668 days	505 days
Distance to Jupiter (in R_J) at the time of the flyby	8.5	3.5
Flight time from Jupiter to Saturn	750 days	585 days
Distance from Saturn (in R_S) at the time of the flyby	2.3	1.07
Flight time from Saturn to Uranus	1,545 days	1,220 days
Distance to Uranus (in R_U) at the time of the flyby	4.1	1.6
Flight time from Uranus to Neptune	1,260 days	1,000 days
Duration of entire flight	11.6 years	9.1 years

The duration of the flight in days to the remaining planets are given in Table 14 for the first and second versions.

TABLE 14.

Destination Planet	Flight duration from Earth (in days)	
	First version	Second version
Jupiter	505	668
Saturn	1,090	1,418
Uranus	2,310	2,963
Neptune	3,310	4,223

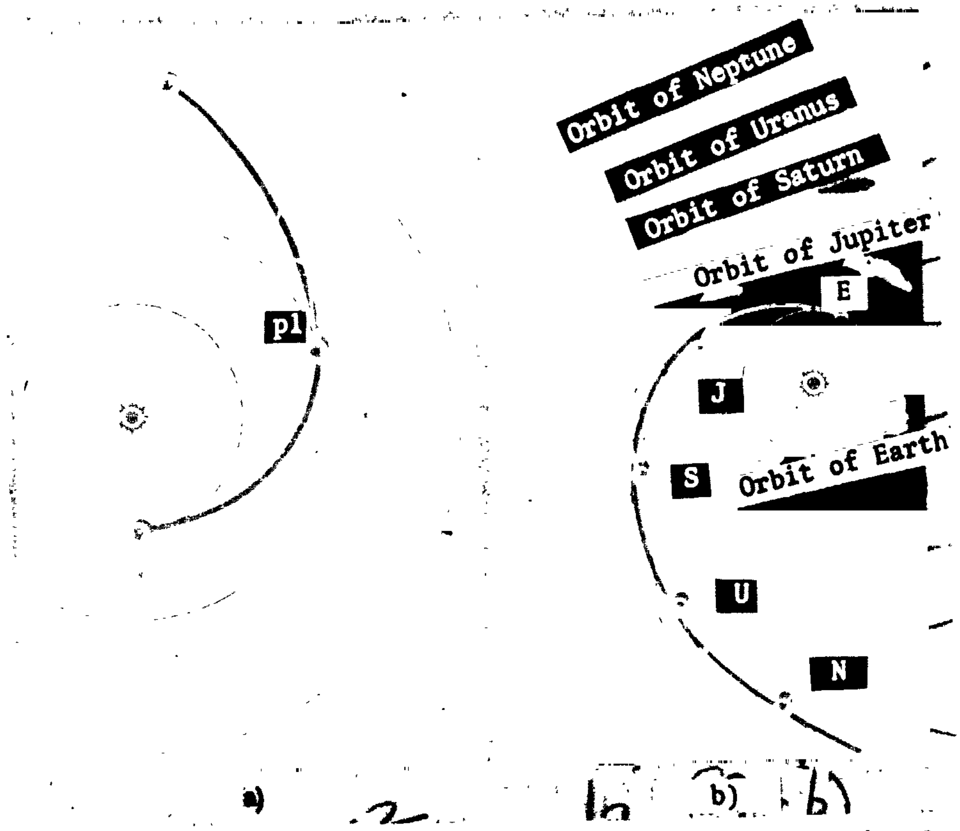

Figure 39. Flights to Distant Planets Using the Gravitational Fields of the Giant Planets: a) Schematic Diagram of the Gravitational Turning of the Trajectory upon a Spacecraft's Passage Near the Planet: I, Flight Trajectory from Planet 0 to Planet 1; II, Spacecraft's Flight Trajectory without Taking into Account the Gravitational Turning; III, Spacecraft's Flight Trajectory after the Maneuver at Planet 1; $\bar{V}_{pl}$, Velocity of Planet 1's Motion Along its Orbit around the Sun; V_1, Spacecraft's Heliocentric Velocity upon Approaching Planet 1's Sphere of Influence; $\bar{V}_{\infty 1}$, Spacecraft's Velocity Relative to Planet 1; $\bar{V}_{\infty 2}$, Spacecraft's Velocity Relative to Planet 1 after Flight in this Planet's Sphere of Influence; v, Angle of the Gravitational Turning of the Spacecraft's Relative Velocity Vector; $\bar{V}_2$, Spacecraft's Heliocentric Velocity after Passing through Planet 1's Sphere of Influence; b) Schematic Diagram of the Flight of a Spacecraft Using the Gravitational Maneuver: I, Actual Flight Trajectory of the Spacecraft; II, Flight Trajectory without Taking into Account the Attraction of the Spacecraft by Jupiter; III, Flight Trajectory without Taking into Account the Attraction of the Spacecraft by Saturn; IV, Flight Trajectory without Taking into Account the Attraction of the Spacecraft by Uranus; and V, Flight Trajectory without Taking into Account the Attraction of the Spacecraft by Neptune. The spheres of influence of the planets are denoted by small circles.

It should be pointed out that the spacecraft's kinetic energy at any instant after its flyby of Jupiter will exceed the energy necessary for it to escape from the Solar System; therefore the spacecraft may become a galactic probe after its flight around Neptune. /141

The optimum dates for the spacecraft's launch in the direction of the planets Uranus and Neptune with a flight around Jupiter lie in the period September-November 1978, but, for a flight to Pluto, the optimum launch dates are June-August of 1976. In addition to the main version of a spacecraft's flight past the indicated planets which has been discussed by us, other versions are given in the references (see Table 15).

TABLE 15.

Version	Which planets should the spacecraft fly past?	Favorable periods for the spacecraft's launch in the 1970s					Next favorable launch year
		1976	1977	1978	1979	1980	
1	Jupiter, Saturn, Uranus, Neptune (main version)	X	X	X			2155
2	Jupiter-Saturn		X	X	X		1996
3	Jupiter-Uranus				X	X	1992
4	Jupiter-Neptune				X	X	1992
5	Jupiter-Pluto		X	X			1989
6	Jupiter-Uranus-Neptune			X	X	X	2155
7	Jupiter-Saturn-Pluto		X	X			2076

On March 3, 1972 American scientists launched the Pioneer 10 spacecraft in the direction of Jupiter. It will complete its flight past Jupiter in December Of 1973; a second spacecraft, Pioneer 11, was launched in April of 1973.

Pioneer 10 should fly 21 months out to Jupiter and cover almost a billion kilometers — such is the extent of the trajectory. The distance between the orbits of the Earth and Jupiter is significantly less, but the spacecraft will move along a curve tangent to the orbits of the Earth and Jupiter. Such a trajectory is the most favorable with respect to energy, since it requires the least initial velocity. It is true that even this minimum velocity is 14 km/sec, i.e., significantly greater than is required in the case of flights to /142 the Moon, Mars, and Venus. An indicative detail is that the Pioneer 10 spacecraft will cross the Moon's orbit 11 hours after launch, while both the automatic and manned lunar craft "reached" the Moon in 3-5 days.

On its journey to Jupiter, Pioneer 10 will have to pass through the asteroid belt between the orbits of Mars and Jupiter. The width of this belt is almost 300 million kilometers. The spacecraft will enter it July of 1972. Based on an estimate by American specialists, the probability of a fatal collision in this belt does not exceed 10%. A "Sisyphus" instrument (a set of four optical telescopes) to record asteroids, as well as a meteoric dust detector, are mounted onboard Pioneer 10.

Pioneer 10 began its scientific work with the Earth: soon after launch the instruments to investigate the outer radiation belt of out planet were turned on.

But the spacecraft will carry out its main task in its flight past Jupiter. Its trajectory has been corrected with the intent that it avoid the exceedingly powerful radiation belt of Jupiter, which, if the spacecraft were to enter, might damage its equipment with ionizing radiation. It will fly by at a distance of approximately 140,000 kilometers from the planet on December 2, 1973.

Thus the most important time of the spacecraft's operation will take place at the end of November and the beginning of December of 1973. The investigation of Jupiter, its satellites, and near-planetary space from the flyby trajectory will continue for about 4 hours. The spacecraft will carry such devices for these purposes as a magnetometer, a plasma analyzer, charged particle detectors, infrared and ultraviolet radiometers, the already mentioned "Sisyphus" device, a meteoric dust detector, and a photopolarometer. Ten photographs of Jupiter and approximately the same number of photographs of its satellites will be taken with the help of this photopolarometer.

The scientists will be especially lucky if they succeed in photographing /143 the so-called "Red Spot" in Jupiter's atmosphere. According to some suggestions, this is an enormous (up to 50,000 km in length) lump of frozen solid hydrogen "floating in the atmosphere".

Very little is known about the nature of Jupiter. It is not even known whether or not Jupiter has a solid surface similar to that of the Earth. There is a suggestion that the gas-like hydrogen of the Jovian atmosphere changes "with depth" into a liquid and then into solid hydrogen under the influence of its tremendous attraction.

Jupiter's attraction will increase Pioneer 10's velocity up to approximately 20 km/sec. This velocity exceeds the third cosmic velocity (16.2 km/sec) necessary to overcome the Sun's attraction. As a result the spacecraft will intersect Pluto's orbit 11-12 years after launch and will escape from the Solar System. Communication with the spacecraft may, as the specialists assume, be maintained as far as 2.4 billion kilometers from the Earth. Pioneer 10 will be at this distance (between the orbits of Saturn and Uranus) approximately 6 years after launch.

The spacecraft's mass is 250 kilograms, and the mass of the scientific instruments is 27 kilograms. The spacecraft is stabilized in orbit by rotation. Six motors with a thrust of 0.5 kilograms of force each, operating on the product of the breakdown of hydrogen, will serve to turn it, orient its axis of rotation, and correct its trajectory. In flight the spacecraft's axis of rotation is in such a position that the narrow-beam antenna with a reflector 2.7 meters in diameter is constantly oriented toward the Earth. Four radioisotope units with a power of 40 watts each serve as the onboard electrical energy sources.

The Pioneer 10 spacecraft will evidently escape from the Solar System; therefore it is impossible to rule out completely the possibility that it may encounter rational extraplanetary beings if they exist at all (true, the probability of such an encounter is vanishingly small). In order to give an idea to these extraplanetarians about the location and time of launch of the spacecraft, and also in general about terrestrial inhabitants, the spacecraft will carry a message drawing having a symbolic rather than an actually practical significance.

It is possible to obtain exceedingly important scientific information if one places a spacecraft into orbit as an artificial satellite of Jupiter. It is true that, in view of the significant energy expenditures required, only highly elongated orbits with a pericenter altitude on the order of 1 Jovian radius and a revolution period of several days are realistic in the near future. A decelerating impulse of more than 15 km/sec is required to launch an artificial satellite of Jupiter into a low circular orbit.

The probing of the giant planet's atmosphere by descent stages of the Venus and Mars type is of great interest. It is true that the problem of entry into the atmosphere, for example, in the case of Jupiter, is exceedingly complex. The problem consists of the fact that the second cosmic velocity (escape velocity) for it is approximately 60 km/sec. But since Jupiter rotates very rapidly about its axis (the linear velocity at its equator is about 13 km/sec), this circumstance will permit decreasing the atmospheric velocity to /144 47 km/sec if the descent stage enters the atmosphere in the equatorial plane at a small angle to the local horizontal and in regard to the planet's rotation. It is true that here, in addition to the energy problem, there are many other difficulties; in particular, the problems associated with thermal protection and the durability of the design, since a spacecraft entering the planet's atmosphere will experience colossal friction heating and enormous overloads.

Natural Orbital Stations

The use of the planet satellites as natural orbital stations is very advisable, especially in studying the planets of the Jovian group, since most of them have families of satellites (see Table 3, p. 22). Some of them, by virtue of their sizes and mass, can serve people as good natural orbital bases to establish placement on them scientific research stations. And this, in its turn, will make it possible to investigate thoroughly the giant planets. Notwithstanding the fact that landing automatic spacecraft on them is completely possible, settlement of these planets by man is completely excluded in the foreseeable future.

The group of so-called Galilean satellites (Io, Europa, Ganymede and Callisto), discovered by Galileo in 1610, and primarily, the most distant of them, the satellite Callisto (see Table 3), present exceptional possibilities for the study of the planet Jupiter. One must assume that systematic observations and investigations of Jupiter, including the probing of its atmosphere through its entire depth, will be initiated from it. Io and Ganymede are equal in size to Mercury and, due to this fact, they can also be reliable bases. The largest satellite of Saturn, Titan, also offers good possibilities for a comprehensive investigation of this planet. Its mass is twice as great than that of the Moon, and it is surrounded by an atmosphere. The satellite Titania of Uranus and Triton of Neptune can also serve well these same purposes. Along with the investigation of the satellites of the planets, one should not exclude such a very interesting possibility as the adaptation of the asteroids for a journey of cosmonauts in "contaminated" regions of space and especially between Mars and Jupiter. Kraft Ehricke suggests using the asteroids as the transporters of spaceships and investigators. Since some of the asteroids move along asymmetrical orbits and periodically approach the Earth, it seems possible to use these asteroids as natural mobile bases. In fact landing on an asteroid with a 1-2 kilometer radius presents no difficulties since the attraction on them is negligibly small. A launch from an asteroid also requires an insignificant energy expenditure.

Which asteroid is most suitable to use for these purposes? Those of them which approach nearest to the Earth are of the greatest interest. Thus, Eros approaches the Earth once every few decades to within a distance of 23,000,000 kilometers, Anur to within 15,000,000 kilometers, Icarus to within 6,000,000 kilometers (the last approach was on June 14, 1969, and the next will occur in 19 years), Apollo to within 3,000,000 kilometers, Geographus to within 2,000,000 kilometers, Adonis to within 1.5 million kilometers, and Hermes to within 0.6 million kilometers (its diameter is about 1 kilometer, and the force of gravity on it is 10,000 times less than on the Earth). /145

Flights near the asteroid with the purpose of photographing them from close distances will become easily achievable in the near future.

Interplanetary spaceships making flights within the confines of the Solar System, both unmanned and manned, will probably have onboard small landing units which will execute a landing on the celestial body being investigated and will remain there for return to the interplanetary spaceships. This is especially important in investigating the giant planets, red hot Mercury, and firey Venus. They will permit probing the atmosphere of the planets and their satellites, investigating the conditions prevailing on the surface of celestial bodies, and solving other problems of a scientific nature.

Flights to the Sun

In the section "Interplanetary Trips to Venus", we pointed out that, in order to reach our diurnal luminary in a flight along the shortest route (along a straight line), a spacecraft should have initial velocity of 31.8 km/sec, making the flight in a direction opposite to the orbital motion of the Earth. Then, leaving the Earth's sphere of influence, its heliocentric velocity (velocity relative to the Sun) will be equal to zero, and its fall into the Sun, which will last 64 days, will begin (Figure 40).

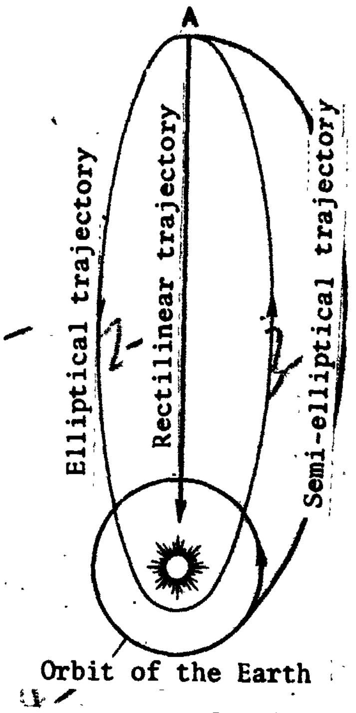

Figure 40. Characteristic Flight Trajectories of an Unmanned Spacecraft in the Vicinity of the Sun. When the velocity is completely negated at aphelion A the spacecraft will appear to be on a rectilinear falling trajectory into the Sun. If the velocity at aphelion A is not completely negated, the spacecraft will move along an eliptical trajectory of approach to the Sun.

If the spacecraft leaves the Earth's sphere of influence in a direction opposite to the orbital motion of our planet with a velocity less than 29.77 km/sec, its heliocentric velocity will prove to be less than the Earth's orbital velocity, and the spacecraft will be directed within the orbit of the Earth along an elliptical trajectory. The aphelion of its trajectory will be at the Earth's orbit, and the perihelion will be at some certain distance from the Sun. Calculations show that, in order to reach a perihelion distance of 0.2 A.U., it is necessary that the spacecraft leave the Earth's sphere of influence with a heliocentric velocity of 12.59 km/sec, which corresponds to an initial takeoff velocity (it is arbitrarily assumed that it is reached at the Earth's surface) of 16.84 km/sec. Thus an approach to the Sun to within a distance of less than 0.2 A.U. requires a significantly greater velocity than the velocity of flights to the most distant planets of the Solar System.

The closest approach to the Sun is theoretically achieved when the probe's orbit touches the edge of the Sun opposite to the point in the Earth's orbit at which our planet was located at the instant of the launch. The period of revolution along such an orbit will be 128 days. This means that perihelion, which the probe crosses at a velocity of 615 km/sec, is reached in 64 days. The necessary launch velocity from the Earth (29.1 km/sec) is theoretically the minimum which guarantees reaching the Sun. /146

Are there no other trajectories which make it possible to reach the vicinity of our Sun with smaller energy expenditures? It turns out that there are. Let us direct the spacecraft along an elliptical trajectory tangent to the Earth's orbit to the periphery of the Solar System. The velocity necessary for this will not exceed the third cosmic velocity — 16.67 km/sec. If the aphelion of the elliptical trajectory is sufficiently distant, the spacecraft's velocity will be so small that the small fuel supply on the spacecraft will be sufficient for the onboard motor to negate it completely. Then the spacecraft will begin its fall into the Sun along a rectilinear trajectory. If the velocity is not completely canceled, the spacecraft will fly towards the Sun along an elliptical trajectory. It has been calculated that, if the spacecraft's aphelion is located at a distance of 20 A.U. from the Sun (beyond Uranus' orbit), the takeoff velocity should be 15.8 km/sec, and the velocity at aphelion will be 2 km/sec. In order to guarantee the spacecraft's falling into the Sun, it is necessary to cancel out this velocity. Thus the energy expenditures are 17.8 km/sec, and the flight will last 33 years (17 years for the spacecraft to move out beyond Uranus' orbit, and 16 years to fall into the Sun).

A flight to the Sun with a perturbing maneuver at Jupiter is of great interest. The trajectory of a flight around Jupiter which would bring the spacecraft into the vicinity of the Sun for an initial takeoff velocity from the Earth of 15.3 km/sec is shown in Figure 41. The spacecraft, flying past Jupiter at a distance of 5.3 Jovian radii from its center, will be repelled towards the Sun and will fly past it at a distance of 0.2 A.U.

In order to reach the vicinity of the Sun, it is assumed that the gravitational influence of Venus is used twice in a single flight. After the first flyby of Venus' sphere of influence, the spacecraft will be put into an orbit whose perihelion is nearer to the Sun than the perihelion of the flight trajectory to Venus. Moving along its new orbit, the spacecraft will /147
again be in Venus' sphere of influence, and emerging from it, it will fly still nearer to the Sun.

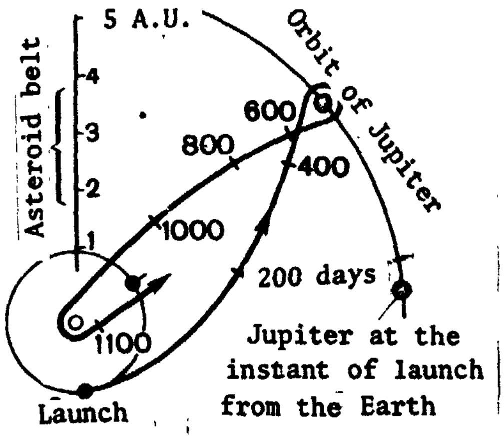

Figure 41. Characteristic Flight Trajectories of a Spacecraft in the Vicinity of the Sun. The trajectory consists of a flight around Jupiter which will bring the spacecraft into the vicinity of the Sun for an initial takeoff velocity from the Earth of 15.3 km/sec. The spacecraft, flying past Jupiter at a distance of 5.3 Jovian radii from its center, will seem to be repelled towards the Sun and will fly past it at a distance of 0.2 A.U.

The values of the energy expenditures and the flight duration of a spacecraft moving in the ecliptic plane with an approach to within a distance of 0.2 A.U. upon completion of a direct flight with a flyby of the spacecraft near Venus and past Jupiter, are given in Table 16.

Still more significant energy expenditures are required for the flight of a spacecraft along a trajectory with an inclination to the ecliptic plane of about 96°. However, it will become possible, in the case of a flight past Jupiter, to attain this goal. Comparative characteristics for a flight utilizing Jupiter's gravitational field and a direct flight are given in Table 17.

It follows from what has been /148
said that the use of the gravitational fields of the planets Venus and Jupiter will make

possible a flight to the vicinity of our Sun with permissible energy expenditures even in the near future.

TABLE 16.

Flight Version	Launch date	Energy expenditures, km/sec	Flight duration, days
Direct flight	any date	9.0	80
Flight past Venus	June 12, 1975	6.9	110
Flight past Jupiter	May 5, 1974	6.85	1,346

TABLE 17.

Characteristics of the Flight	Flight Version	
	Flight past Jupiter	Direct flight
Launch date	May 20, 1979	any date
Total flight duration in days	1,039	172
Accelerated impulse from an Earth satellite orbit, km/sec	7,915	28.6

It has been reported in the press that launches of the Helios solar probes are planned for July of 1974 and for October of 1975 with the help of the Atlas-Centaur-Berner-2 American rocket system. The probes are being constructed in West Germany. The mass of each is about 250 kilograms. Their distance from the Sun at perihelion should be approximately 0.3 A.U. (even 0.2 A.U. with the use of the Titan-3D-Centaur-Berner-2 booster rocket), and at aphelion — 1 A.U. It is assumed that the probe's instruments will transmit results of ten different experiments associated with the investigation of the interplanetary gas, the solar wind, magnetic field, micrometeorites, electromagnetic missions in various spectral regions, and cosmic rays. /149

A plot of the dependence of the initial takeoff velocity from Earth on distance from the Sun is given in Figure 42.

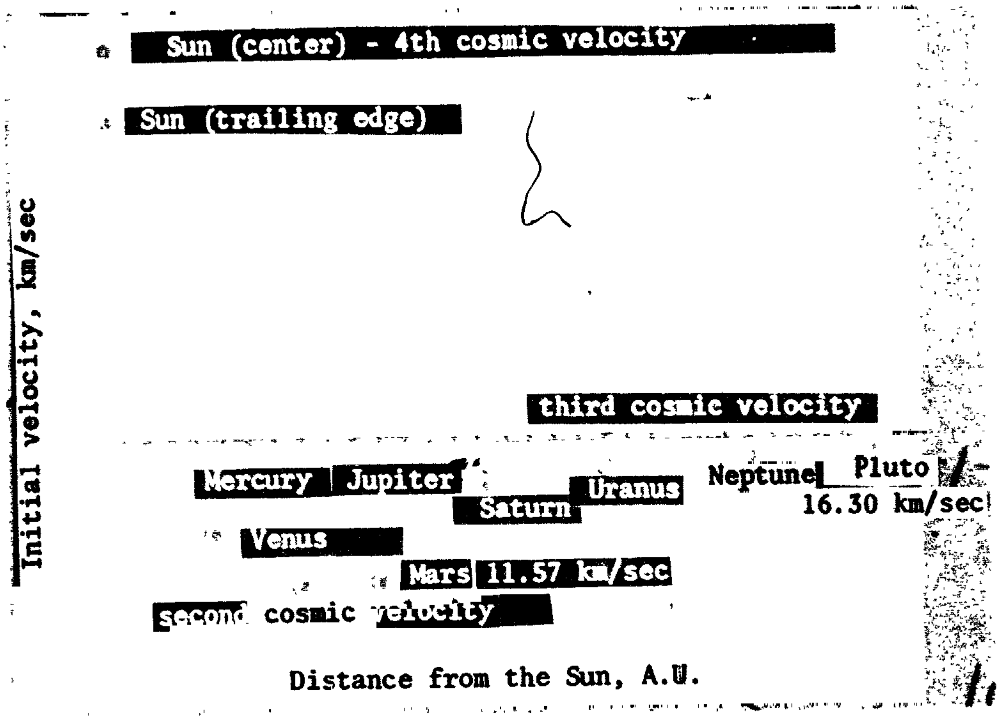

Figure 42. A Plot of the Dependence of the Initial Takeoff Velocities from Earth on the Distance from the Sun. The scale of the section up to 1 A.U. along the abscissa is 20 times larger than the scale of the rest of the abscissa. Along with the data referring to the orbits of artificial planets which lie inside the Earth's orbit (their aphelia at a distance of 1 A.U. from the Sun), data are given for the orbits of the outer artificial planets (perihelia at a distance of 1 A.U. from the Sun). Each new step in the advance of the perihelia of the inner orbits towards the Sun requires a larger increase in the initial velocity. In the case of flights to the edges of the Solar System, the alphelia are shifted colossal distances to negligible increases in the initial velocity. This is clearly evident, although the scales of the distances along the abscissa differ by a factor of 20 for the inner and outer orbits.

CHAPTER 6.
"LOCOMOTIVES" OF THE SIDEREAL PATHS

The problem of the energetics of the spacecraft's motion is a fundamental in cosmonautics. No matter where a spacecraft is directed, it absolutely has to have an energy source. It is vital not only for the operation of the main power units which make it possible for the spacecraft to move in outer space but for the functioning of the onboard systems and scientific instrumentation. If investigators were onboard a spaceship, energy for their life-support system would be necessary in addition. /150

Energy systems used in space differ from the terrestrial ones in that they must produce as much energy as possible with as small a weight and volume as possible. In addition, specific requirements are imposed on them such as exceedingly high efficiency and reliability, the capability of operating for a considerable length of time, and an absolute invulnerability under the conditions of an extended interplanetary trip. Cosmonautics already has available now a large arsenal of rocket motor systems utilizing various sources of energy. It is true that there is still no universal source of energy for interplanetary spacecraft, and therefore the most suitable of them are chosen to fulfill this or the other specific task. Thus, for example, in order to place the heavy booster rocket of a spacecraft into a near-Earth orbit, its motors must develop an enormous thrust force exceeding its weight; otherwise for the control of a spacecraft's flight, and completely "negligible" thrust of the motors is necessary to orient and maintain the spacecraft in a specified stabilized regime.

According to the energy type used, the motor assemblies of a spacecraft are divided into four types: thermal chemical, nuclear, electrical, and solar. /151

On the basis of their thrust characteristics, it is possible to divide them into two large groups: motors of large thrust and motors of small thrust. Motors for non-continuous operation which transmit to the spacecraft large accelerations and permit it to accomplish a takeoff from the surface of planets belong to the first group. Motors for continuous operation which produce comparatively low thrust force and transmit to the spacecraft all accelerations constitute the second group.

Let us briefly discuss each of these types of motors.

Thermo-Chemical Rocket Motors

It is well-known from everyday experience that atmospheric oxygen plays the most active rôle in an internal-combustion engine, the firebox of a steam boiler, and in the combustion chamber of a turboreaction motor — everywhere where burning, for example, of gasoline, kerosene, coal, wood, and so on occurs. There is no burning without it. There is no air in outer space, and perhaps no gaseous oxygen. On what will the space rocket motors operate?

Let us carry out the following experiment. Let us pour liquid oxygen into a container of kerosene. Momentarily a flame will flare up, and burning will take place without the participation of atmospheric oxygen, i.e., one component of the fuel will burn in the other. But since the qualitative role of these materials is different, since their combustion is a chemical reaction of oxidation, then in order to emphasize this distinction, one of the components of the rocket fuel which is oxidized is called the fuel and the other, the oxidizer.

Alcohol, kerosene, benzene, analine, and hydrozene are used as the fuel, and liquid oxygen, nitric acid, hydrogen peroxide, and liquid flourine as the oxidizer, in liquid rocket motors (LRM).

The fuel and the oxidizer of an LRM are stored separately in special tanks, and they are supplied to the combustion chamber by pumps. Here a temperature up to 3,000°C and a pressure of 50-60 atmospheres is developed as a result of their combination. The combustion products expand and swiftly flow out through a special nozzle. Repelled from the motor's housing, they produce a reactive force which moves the rocket in a direction opposite to the outflow of the gaseous stream. The larger the energy liberated upon combustion of the fuel, the larger the portion of this energy which is converted into kinetic energy and the larger the outflow velocity of the gases, and, consequently, the thrust force of the rocket motor, will be.

About 70 years ago (in 1903), K. E. Tsiolkovskiy first established the dependence of the final velocity which a rocket can reach on the amount of fuel onboard the craft and on the outflow velocity of the products of its combustion (gases) from the rocket motor. He proceeded in his approximate calculations on the assumption that the force of gravity and air friction are absent and that the motion itself of the device is caused only by the expulsion of the exhaust gases. /152

He expressed the dependence which he found by the equation

$$V_{final} = c \cdot \ln \frac{M_{initial}}{M_{final}} . \tag{12}$$

Here V_{final} is the rocket's final velocity, i.e., that velocity which the rocket acquires after the combustion of all the fuel stored in it when it accelerates in "free" outer space. This is usually called the characteristic or ideal velocity, emphasizing nevertheless that although in reality it is not achieved, it would be entirely possible to reach it under certain ideal conditions. It is measured in meters per second or kilometers per second, c is the outflow velocity of gases from the rocket motor measured in meters per second or kilometers per second, $M_{initial}$ is the rocket's initial mass, its so-called launch mass, which includes the mass of the rocket assembly, the fuel supply, and the useful payload, M_{final} is the rocket's final mass, i.e., its mass after consumption of the fuel stored in it, and ln is the natural logarithm which is related to the base-ten logarithm by the relation ln N = 2.3 log N (here N is any number).

It is evident that the rocket's initial mass is equal to

$$M_{initial} = M_{final} + M_{fuel},$$

where M_{fuel} is the mass of the fuel. Having substituted into (12), we obtain

$$V_{final} = c \ln \frac{M_{final} + M_{fuel}}{M_{final}} = c \ln \left(1 + \frac{M_{fuel}}{M_{final}}\right). \quad (13)$$

The ratio $\frac{M_{fuel}}{M_{final}} = z$ is called the Tsiolkovskiy number.

It is fully evident that the more fuel the rocket has, the larger the number is, and naturally, the higher its final velocity is. We note that we are not talking about an absolute fuel supply, but about the ratio of the fuel mass to the mass of the useful payload and the rocket structure. Thus it follows that, in order for a rocket to be able to reach as high a flight velocity as possible, its builders must strive to make the rocket as light as possible so that as large a fraction as possible of the initial mass can be in the form of fuel and useful payload. If one takes into account the gravitational force of a celestial body and the resistance force of its gaseous envelope, a rocket's final velocity is determined by the expression

$$V_{final} = Kc\ 2.3 \log \frac{M_{initial}}{M_{final}}, \quad (14)$$

where K is some coefficient (K < 1).

The most important characteristic of a rocket motor is the velocity of the exhaust gases. The best kinds of chemical fuels used in contemporary LRM (liquid rocket motors) are capable, upon combustion, of producing a stream of gas with an exhaust velocity as high as 5,000 m/sec. If one takes into account the fact that a booster rocket's mass ratio is also very restricted, the difficulties in obtaining a high flight velocity for rockets will become completely evident. Even if the rocket did not at first carry a useful payload and consisted only of the "empty framework" and fuel, this ratio could scarcely exceed the number 10. We will clarify what this means with the following examples: the mass of the contents of an egg, i.e., the white and the yolk taken together, only exceed the mass of the shell by a factor of 10; the mass of an ordinary bucket is about a kilogram, and it holds no more than 10-12 liters of water; approximately the same ratio obtained for a railroad tank —it can hold 13-15 times more liquid that it itself weighs. Thus one should bear in mind the fact that neither a bucket nor a tank have heavy and cumbersome power units on them nor any other complicated systems controlling not only the operation of the motors but the flight of the rocket with its useful payload on board. Consequently a rocket's skin should be very light and simultaneously /153 durable enough to withstand the dynamic overloads in flight. Based on the cited formulas it is not difficult to compute the maximum velocity possible. As an example let us take a mass ratio equal to 10 at a gas exhaust velocity of 3,000-3,5000 m/sec. The maximum attainable velocity is 8.05 and 10.35 km/sec, respectively.

We pointed out earlier that the higher the exhaust gas velocity, the higher the rocket's flight velocity. This is on the one hand. On the other hand, the higher the exhaust gas velocity, the greater the specific thrust will be — one of the main indicators of a rocket motor's efficiency. Since we have not encountered this index previously in this book, let us discuss it in somewhat more detail.

The thrust of a motor is related to the exhaust has velocity by the known formula

$$F = \frac{G}{g} c, \tag{15}$$

where $\frac{G}{g}$ is the consumption per second of combustible fuel and c is the exhaust gas velocity. Thus an increase in the exhaust gas velocity and an increase in the rate of consumption of the working medium raise the thrust. But the perfection of the motor and the efficiency of its operation are characterized by the specific thrust, i.e., the thrust which can be achieved if one consumes 1 kg of fuel in one second, and it is expressed by the formula

$$j = \frac{F}{G} = \frac{G}{gG} c = \frac{c}{g} . \tag{16}$$

If the thrust force determines the thrust equipment of the rocket and depends on the absolute dimensions of the motor, the specific thrust shows the efficiency of the use of a single kilogram of fuel in a given motor. The higher a motor's specific thrust, the less fuel is expended to attain the same total impulse of the motor. It characterizes the economy of the thrust system and is determined by the perfection of all processes taking place in the motor. This means that, in the case of identical fuel weight and dimensions of the motors, one could be preferable which has the higher specific thrust. It is evident from equations (15) and (16) that the thrust force of a RM (rocket motor) and its economy depend on the rate of rejection of reactive mass. Therefore an increase in this rate is the object of the tireless efforts of the creators of spacecraft. /154

The exhaust gas velocity from the nozzle of a RM (rocket motor) depends on the temperature and molecular weight of the gases. The higher their temperature is, the greater the velocity; on the other hand, it is desirable to have as small a molecular weight of the combustion products (working medium) as possible: the exhaust velocity increases as it decreases. From this point of view, liquid hydrogen is considered the best fuel.

It possesses a high heat-resistance, which provides for a high temperature for the combustion products, and it has the lowest molecular weight of all the materials known on Earth, In addition, the specific impulse shows physically what thrust a motor will produce for each kilogram of fuel consumed per second.

Thus, if an exhaust gas velocity is taken equal to 3,500 m/sec, then a motor in which, let us assume, 100 kg of fuel burns each second, will develop a thrust of $F = 100 \times 3500 = 350$ newtons[14]. The specific thrust is $\frac{3500}{9.8} = 355$ kg·sec/kg. The larger the specific thrust, the lower the specific fuel expenditure. Due to this it appears possible to decrease the ratio of a rocket's initial mass to its final value. At the present time approximately 2.5-3 grams of fuel is expended for each kilogram of thrust acting for one second. It is not difficult to calculate that it is necessary to expend 2.5-3 kg of fuel per second, and 150-180 kg per minute, in order to generate one ton of thrust. But since the thrust of contemporary rocket motors reaches an enormous value figured in hundreds and thousands of tons, very large fuel supplies are necessary for them. Therefore contemporary rockets, figuratively speaking, are very "voracious" and can be conceived in the literary sense to be a flying tank. In order to convince one's self of this, let us make some very simple calculations. Let us assume that a rocket has 800 kg of fuel and its final mass is 200 kg. With an exhaust gas velocity of 3,000 m/sec and with $K = 0.7$, the rocket's final velocity will be $V_{final} = 0.7 \cdot 3{,}000 \ln 5 = 0.7 \cdot 3{,}000 \cdot 1.61 - 3{,}381$ for m/sec. As we see, this is an insufficient velocity even to place the rocket into orbit as an Earth satellite. This leads to the conclusion that, even using the best chemical fuel[15], such gigantic rockets are required for interplanetary trips as /155
are impossible to construct at the contemporary level of technology. Thus if we take the useful payload mass (i.e., the mass of the crew and everything necessary for its operation and vital activity) to be ten tons, the rocket's launch mass in the case of a flight, for example, to Mars and back would be more than 25,000 tons. As we see, the takeoff weight of "chemical" rockets for such a flight become literally fantastic. But mankind is beginning to populate space in earnest. People are trying to construct scientific stations on the Moon, they are striving towards Mars and Venus, and today they are even contemplating flights to the more distant worlds of the solar system and beyond its limits. Where does it all lead?

The fact that a rocket's mass is decrease in proportion to the fuel expenditure favors an increase in the rocket's flight velocity, and due to this, the acceleration grows continually under constant thrust. In addition decreases in the rocket's mass can be achieved if from time to time remaining unnecessary empty tanks, spent motors, parts of the framework, and so on were jettisoned from the rocket. After jettisoning, all these parts would no longer burden the rocket with "dead weight", hindering its acceleration. The idea of creating such a rocket, called a multi-stage rocket, was

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[14]The dimensionality of the specific thrust is given in seconds in the literature. But the physical meaning is lost with such a dimensionality.

[15]Liquid hydrogen in combination with liquid oxygen gives a specific impulse of about 450 seconds. Contemporary LRM (liquid rocket motors) operating with non--cryogenic fuel (for example, hydrocarbons) have a specific impulse not exceeding 350 seconds.

first advanced in 1929 by the founder of cosmonautics, K. E. Tsiolkovskiy (Figure 43).

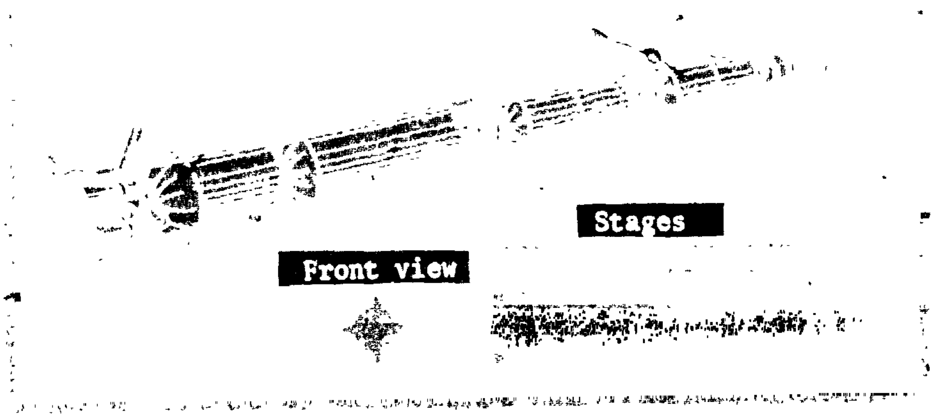

Figure 43. Schematic Diagram of a Multi-Stage Rocket: 1, Liquid Rocket Motor of the First Stage; 2, Stabilizer; 3, Fuel Tank of the First Stage; 4, Oxidizer Tank of the First Stage; 5, Liquid Rocket Motor of the Second Stage; 6, Fuel Tank of the Second Stage; 7, Oxidizer Tank of the Second Stage; 8, Third Stage Liquid Rocket Motor; 9, Third Stage Fuel Tank; 10, Third Stage Oxidizer Tank; 11, Instrument Compartment with Instrumentation of the Control System; 12, Useful Payload; 13, Nosecone; 14, Mechanism for Separating a Space Object; 15, Junction Between the Second and Third Stages and 16, Junction Between the First and Second Stages.

The rocket consists of separate stages, and in flight when the entire fuel supply has not yet been consumed but only the fuel located in the first stage tanks has been consumed, elements of the structure which have been used and are unnecessary for subsequent flight are discarded. While the motors of the first stage are operating, we can consider the remaining part of the rocket as useful payload. After the separation of the first stage, the second stage motors operate. They add their contribution to the already existing velocity, and as a result the total velocity becomes greater.

According to equation (13), the velocity after the termination of operation of the first stage motors is equal to

$$V_1 = c_1 \ln (1 + Z_1).$$

The velocity at the end of operation of the second stage is equal to

$$V_2 = V_1 + c_2 \ln(1 + Z_2) \text{ or}$$

$$V_2 = c_1 \ln(1 + Z_1) + c_2 \ln(1 + Z_2).$$

The velocity at the end of operation of the n-th stage is

$$V_n = c_1 \ln(1 + Z_1) + c_2 \ln(1 + Z_2) + \ldots + c_n \ln(1 + Z_n).$$

Here $Z_1 = \dfrac{M^1_{fuel} + M^0_{empty}}{M^0_{empty}}$,

where M^1_{fuel} is the mass of the first stage's fuel, and M^0_{empty} is the mass of the entire rocket without the first stage's fuel, and

$$Z_2 = \frac{M^{11}_{fuel} + M^{11}_{empty}}{M^{11}_{empty}},$$

where M^{11}_{fuel} is the mass of the second stage's fuel and M^{11}_{empty} is the mass of the rocket without the first stage and without fuel used in the operation of the second stage motors. If we take $c_1 = c_2 \ldots c_n = c$, and $Z_1 = Z_2 \ldots Z_n = Z$, the formula takes the form

$$V_n = nc \ln(1 + Z).$$

If we take into account the operation of the forces of gravity and air resistance, the final equation for the velocity which a multi-stage rocket will acquire takes the following form

$$V_n = nkc \ln(1 + Z) \qquad (17)$$

Let us discuss in a specific example the advantages of a multi-stage rocket. /157
Let us suppose that the problem is posed of imparting the first cosmic velocity (circular orbit velocity around the Earth) to a rocket. It is built so that the fuel mass in each of its stages amounts to 80%, while the remaining 20% goes for the rocket itself. Let us take the exhaust gas velocity of all the motors to be 3,000 m/sec. Let us consider that the coefficient k also remains constant at each stage. A calculation shows that under these conditions, as has already been shown above, the rocket will develop a velocity of 3381 m/sec towards the end of operation of the first stage motors. After the termination of operation of the first stage motors, the first stage is jettisoned, and the remaining parts of the rocker continues its flight. Since the flight of this rocket begins not from a state of rest but from a velocity of 3,381 m/sec, its terminal velocity is equal to

$$V_2 = V_1 + V_1 = 3381 + 3381 = 6762 \text{ m/sec}.$$

With an exhaust velocity of c = 3,500 m/sec and c = 4,000 m/sec, respectively, we obtain V_2 = 7,900 m/sec and V_2 = 9,000 m/sec.

And so the solution of the problem of attaining the first cosmic velocity has been found. In order to obtain still greater velocities, it is necessary only to increase the number of stages. However in the transition even from single-stage rockets of low mass to heavier ones, the designers have been confronted with a number of significant difficulties. They consist of the fact that, as the linear dimensions are increased for example, by a factor of 2, the volume and mass of the rocket increase by a factor of 8, and the transverse cross-section of the construction of its elements increases by a factor of 4. Consequently the mechanical resistances exerted by the inertial forces increase by approximately a factor of 2. Therefore an increase in the dimensions and mass of a rocket can not be attained by simply reproducing it in a larger scale. Here is why, even at the dawn of the development of rocket technology, there was conceived among the designers such a popular phrase as: "we must be jewelers in our work". It has not lost its significance up to the present time. It is completely understood that the difficulties pointed out by us in the creation of multi-stage rockets and the very restricted possibilities of chemical fuel in increasing the exhaust velocity of its combustion products lead to the fact that rockets operating on chemical fuel do not permit attaining the velocities necessary for the flights of expeditions of investigators along interplanetary trajectories. Therefore the necessity arises of creating rocket motors which operate on different principles. In this respect nuclear motors offer great prospects.

Nuclear Rocket Motors (NRM)

It was shown earlier that one the main inadequacies of rocket motors operating on liquid fuel is associated with the limitations on the attainable size of the exhaust gas velocity. And this is because the working medium itself, by burning, produces the thrust. There is the possibility in a nuclear motor of separating the source of energy and the working medium and, by virtue of this, increasing the specific thrust. The working medium, for example, is liquid hydrogen passing through the active zone of a nuclear reactor; it is heated to a higher temperature. The rapidly expanding gaseous hydrogen flows out of the rocket motor at a high speed. An increase in the fuel density permits one to decrease its dimensions, and consequently the mass of the rocket's capacity. Thanks to this, it is no longer necessary to worry about an oxidizer, and therefore it is necessary to use only a single liquid with a comparatively low molecular weight and a rather high density. And this is very advantageous, since a decrease of the molecular weight by a factor of 2.25 increases the exhaust velocity by a factor of 1.5. The active zone of the reactor (where the fission of the nuclei and the deceleration of their fragments, transformed into heat, occurs) can be of 3 types: solid, liquid, and gaseous. /158

At the present time an NRM (nuclear rocket motor) having a solid active zone is being developed in the USA. With a thermal power for the reactor of 1,500 megawatts, it will give a thrust of 33 tons and a specific impulse of about 850 seconds. However such a motor has one main drawback: the degree of heating of the hydrogen in its reactor is limited by the melting temperature of the fissionable material. Due to this the maximum attainable value of a specific impulse cannot exceed 900 seconds. We note that the most highly efficient NRM (nuclear rocket motor) operating on hydrogen and oxygen at the present time has a specific thrust of the order of 450 seconds.

NRM with a liquid active zone permit increasing the specific impulse to 1,300-1,500 seconds. But the melted nuclear fuel in it, which fumes intensely, will enter the hydrogen and be ejected along with it to the outside, which will lead to radioactive contamination of the surrounding medium.

A motor with a powder reactor may have intermediate characteristics between those of the solid-phase and liquid-phase NRM. The fissionable material in it is in a finely-divided state.

The theoretically attainable value of the specific impulse in a gas-phase NRM is 2,000-2,500 seconds. The comparative characteristics of NRM of all 4 types are cited in Table 18.

TABLE 18.

Type of NRM	Specific impulse, c	Working medium		Temperature of the active zone, °K
		Temperature, °K	P, atm	
Solid phase	900	3,000	70	3,300
Powder-phase	1,100	3,700	70	3,870
Liquid-phase	1,500	5,800	280	8,570
Gas-phase	2,500	16,800	1000	78,500

One more indicative characteristic in comparing these types of power plants consists of the fact that the greater the rocket's initial mass and the specific thrust of the NRM (nuclear rocket motor) in comparison with the specific thrust of a LRM (liquid rocket motor), the greater the economy in the mass of the nuclear rocket due to a decrease in the mass of the working medium. And advantage in mass is a matter or primary importance in cosmonautics. /159

These are the main advantages of this type of motors which are considered, not without reason, as the key to the investigation and conquest of the celestial bodies of the solar system. It is now even impossible to imagine manned expeditions to the planets without the use of the atom's energy.

However, as is evident from the cited table, there are many serious obstacles in the path of creating such motors. The working medium must heat up as the result of the reactor's heat exchange. This means that the material of the reactor must be heated up to still higher temperatures. This requires very heat-resistant materials. The necessity of transferring enormous amounts of heat results in a significant increase in the dimensions and mass of nuclear motors. In addition to this, it will scarcely be possible in the near future to equip such a motor with sufficient biological protection — fielding of a desirable mass and possessing the necessary effectiveness. Therefore in order to avoid radioactive contamination of the atmosphere, it is advisable to use nuclear motors not in the first stage but in the intermediate stages of a multi--stage rocket. If one adds to this the fact that, to launch such a cumbersome and heavy machine into a near-Earth orbit will not be easy, it becomes clear how necessary an interplanetary orbital station is, on which the nuclear motor can be assembled. In fact the possibility is not excluded that the assembly of the nuclear stage will be carried out in near-Earth orbit, to which its parts will be delivered from Earth by LRM (liquid rocket motor) craft.

The technical difficulties enumerated above and others as well do not permit the introduction yet of atomic motors into space exploration. However, there is no doubt that these difficulties will be overcome and nuclear motors will expand the possibilities of solving many problems of space navigation.

Thermoelectric Rocket Motors (TRM)

At the present time this class of motors is being intensively developed, since the promise a multitude of advantages for cosmonautics. The thing is that the thrust of such motors is produced by virtue of the outflow, not of combustion products, as in thermochemical motors, or the heating of a material, as in nuclear motors, but as the result of the outflow of a plasma[16].

It has already been known for a long time that matter exists in 3 states: /160
the solid, the liquid, and the gaseous. In recent years attention has been turned more and more to an unusual fourth state of matter which is called plasma. Just what is this? In the solid state atoms and molecules occupy a rigidly specified position, and it is not easy to displace them. In a liquid, they have a somewhat greater but all the same limited freedom of motion, since the intermolecular distances and the volume of the liquid are almost unchangeable. In a gas the molecules and atoms shift about freely, but within the atoms all the electrons move along their orbits. In a plasma part of the electrons from the outer shell of the atoms is torn loose and acquires complete freedom of motion. Having lost part of their electrons, the atoms and molecules acquire a positive charge and become ions. Thus a plasma is matter consisting of a mixture of positively and negatively charged and neutral particles. It, similar to a metal, conducts an electrical current well. And if it is acted on by an electromagnetic field, a plasma will move in a similar manner to a conductor in which a current is flowing moves in an electrical motor. Thus in plasma motors the flow takes place, not due to a pressure differential between the combustion chamber and the outside, but due to electromagnetic forces. Hence it appears possible to accelerate particles of the working medium to hundreds of kilometers per second.

[16]The term "plasma" was suggested by the American physicist I. Langmuir in 1924 and was adapted by him from biology. More than 90% of all the matter of the Universe is in the form of plasma, and only 0.1% goes into the solid state.

Specific impulse values provided by various thermoelectric rocket motors (TRM) are as follows: electric arc — up to 1,500 seconds (the acceleration of the working medium in it is purely thermal); magnetohydrodynamic (magnetohydrodynamic motors — MRM) — up to 6,000-7,000 seconds. In it the energy is imparted to the working medium by means of the Lorentz force, which arises when a magnetic field interacts with an electric current in the plasma (the current flows at right angles to the magnetic field of the accelerator). The ion thermoelectric rocket motor gives a specific impulse as high as 20,000 seconds.

In order to clarify the nature of the operation of an electric rocket motor, let us discuss as an example ion motors in which the reactive thrust is produced by a flow of ions accelerated by a magnetic field. An ion motor consists of three parts: the ion generator, the ion accelerator, and a system for neutralizing the space charge. How does such a motor operate?

Pairs of cesium, rubidium, or of any other easily ionized material, coming into contact with a heated tungsten surface, are heated up to 800°C and, by losing electrons, form positively charged ions. When they reach the accelerator, which consists of electrodes to which a voltage of tens of thousands of volts is applied, the ions acquire an enormous exhaust velocity (as high as 200 km/sec), and due to this a reactive thrust is produced. But since the ions leave the rocket but the electrons remain in it, the rocket is negatively charged within a certain time to a rather high potential (of several thousand volts). Due to this it can itself be the accelerating electrode for a beam of ions, but it will accelerate them in the opposite direction, and they will obediently return, negating all the effort expended. To prevent this, neutralization /161
of the ion beam is necessary.

In order to accomplish this, a special neutralizer — an electron emitter — is incorporated into the motor's design. Electrons emitted from it are picked up and ejected to the outside through a special device in an amount equal to the amount of ions and with the same speed. As a result of ejecting a neutral plasma, the spacecraft acquires an acceleration on the order of 10^{-2}-10^{-4} and sometimes less, i.e., tens and thousands of times less than the acceleration due to terrestrial gravity. This means that each second the device's velocity will increase in all by several millimeters, and in some cases tens of millimeters per second. Therefore a spacecraft equipped with such a motor would not be able to take off from the Earth's surface. It would not even quiver at the launch position when the motors were turned on. This makes them unsuitable not only for taking off from the Earth but also in case an appreciable aerodynamic resistance of a celestial body's gaseous envelope is present. Therefore launch of a device equipped with electric rocket motors must take place from a near-Earth orbit.

The flight trajectory of a spacecraft with an electric rocket motor will be a gradually unwinding spiral. Since the acceleration of the spacecraft takes place along the tangent to its orbit, i.e., almost perpendicularly to the direction of the force of gravity, the energy loss in overcoming the forces of gravitation becomes minimal.

And since, in the case of an unwinding spiral, the device's altitude above the planet will be continually increasing, the velocity necessary for it to break away" from the planet will continually decrease. And this is completely understandable! In fact as the altitude increases, for example, above the Earth's surface, the parabolic velocity (second cosmic velocity) decreases!

At a certain altitude the device's velocity will exceed the parabolic velocity, the spiral will change into an ellipse, and the spacecraft will depart on its interplanetary trajectory.

Electrical energy is necessary in order to create the working medium and produce the thrust for such a motor. An onboard nuclear reactor can give this electrical power. Although no temperature restrictions exist in plasma motors, too high exhaust velocities of the plasma are inadvisable, since they would require enormous power from the electrical energy generator, as the energy expended is proportional to the exhaust velocity. The mass of the power plant would increase far more than the thrust (which is proportional to the first power of the exhaust velocity), and as a result the device's acceleration would be greatly decreased.

Since TRM (thermoelectric rocket motors) include an energy converter similar to an atomic electric station, its own mass is very significant in the general balance of the spacecraft's masses. Therefore in addition to the value of the specific impulse, the specific mass is very important for low-thrust motors, i.e., the mass of the thrust system per each unit of its /162
electrical power output.

At the present time their use is assumed to be expedient if a thermoelectric rocket motor has a specific mass no more than 15-20 kg of force/kilivolt.

The very serious inadequacy of such motors is the necessity of releasing the heat excess generated by the nuclear reactor, since it is not removed by the working medium and is not transported away by c nvection to the surrounding medium. One can remove it only with the help of special radiators having a very large radiating surface. Spacecraft equipped with electric rocket motors possess a very important advantage — a large load capacity. According to the calculations of scientists, their useful payload is 1/4 or 1/5 of the initial mass, while the useful payload of spacecraft using thermochemical motors is only 1/10 or 1/15 in all of their launch mass.

An exceptionally important advantage of electroreactive motors is the large performance reserve and the simplicity of their regulation within wide limits by means of varying the electrical supply parameters. These and other advantages make their application very promising on spacecraft having an extended flight duration in the case of the transporting, for example, of different kinds of loads and equipment to other celestial bodies.

One should also not exclude the possibility of obtaining in space almost "free" electrical energy by means of the interplanetary ionized plasma. If such a plasma is a rather rare state of matter on the Earth, it is just the opposite in the Universe, where the major mass of material is ionized. There it occurs in two forms well-known to us: in the form of a "steady-state gas" consisting of charged particles which move chaotically at comparatively low velocities, and in the form of the so-called "solar corpuscular streams" which emanate from our Sun at a speed of several hundreds, and sometimes even thousands, of kilometers per second. In this plasma ocean interplanetary liners equipped with electroreactive motors will be able to "swim" infinitely, completing extended space trips almost without expending energy taken from the Earth, There is no need to dwell on how great the role of such motors will be in settling the Universe.

It was reported in the press in October of 1969 that Soviet scientists at the Soviet "Yantar'" automatic station first recorded an unprecedently high exhaust velocity from the nozzle of an electric rocket motor of a gaseous reactive stream — 120 km per second! And the first tests of electric rocket motors under actual conditions of spaceflight were carried out on the Soviet automatic station "Zond-2" as early as in 1964.

Solar-Sail Motors

This is a special type of low-thrust motor (though, it is not a reactive motor). The Russian physicist P. Lebedev proved experimentally in 1899 that solar light exerts pressure on objects. The amount of this pressure is determined by the angle of incidence of the rays on the surface and its reflectivity. It is assumed that the solar rays would press with a force of about 1 kg of force on an ideally reflecting mirror with an area of 1 square kilometer positioned in the Earth's orbit, and solar rays incident on an absolutely black object absorbing all the radiation would exert a pressure one-half as great. /163

A quarter of a century ago the Soviet scientist F. A. Tsander advanced the original idea of using this "solar wind" to move spacecraft which had a sail attached to them — a wire framework covered by aluminum foil. The smallest particles of light, photons, striking the mirror surface of the sail, are reflected from it and simultaneously press against the sail, pushing it forward. Already today "interplanetary sailing yachts" are being designed, and experiments are being carried out with a special film — the "sail-cloth" of the future. The sail's material should possess unique properties. If the sail reflects practically all the solar radiative flux striking it, its temperature will drop to absolute zero. The reason for this is radiation from the shadowed surface. Consequently, the "sail-cloth" would not be harmed by ultralow temperatures. In addition, it should resist such specific conditions as space radiation, the abrasive actions of space dust and meteoric objects, the gradual evaporation of material in a vacuum, and so forth. One must assume that sailing ships will take their place in the upcoming space fleet. It is possible here to draw a certain analogy with the sailing frigates which once navigated over the extensive watery spaces, using wind power. Mounted on interplanetary liners, space sails will be able to serve them in case their main motors become inoperable.

We point out in conclusion to this section that, considering the advantages of the different types of motors in a variety of combinations, it is possible to create space rocket aggregates which will permit the successful solution of the most varied problems of cosmonautics.

Space Rocket Aggregates

Glancing at a space rocket ready for launch, you are struck not only by its size but by the entire complexity of its construction. This is indeed the apotheosis of human genius! And this entire space skyscraper has been created only for the sake of its apex. Precisely there, at the very nose of the rocket, under a protective envelope is what is called "useful payload" in the language of the scientists. This may be an artificial Earth satellite, a manned spaceship, or an automatic interplanetary spacecraft. In order to deliver this, figuratively speaking, "crumb" into space, this multi-stage construction, to which is attached the "good" but clearly "secondary" name of booster rocket. An amazing metamorphis takes place with it during its flight from launch to its injection, for example, into orbit of an Earth satellite and upon its return to Earth. Several stages, and then the satellite ship, are successively separated from it along the section of the injection into orbit of an Earth satellite. When it returns to Earth, prior to re-entry into the atmosphere, the spaceship itself has been separated into 2 or more parts of which only a single cabin with the crew, or as it is otherwise called, the descent stage, /165 reaches the Earth's surface, jettisoning prior to the landing a few more structural items.

If the spacecraft base places into an interplanetary trajectory an automatic spacecraft which, having flown around the Moon, returns to Earth, it is /166 modified even more (the Soviet automatic spacecraft Zond-5, 6, 7 and 8). But both the manned and the unmanned spacecraft designed for landing on the Moon and return to the Earth are subject to an incomparably greater change. (The Soviet automatic spacecrafts Luna-16 and Luna-20 and the American manned Apollo spaceships.) It is completely understandable how the following question arises: what should be the spacecraft which provides for the flight of an expedition of investigators to the planets of the Solar System?

A diagram is presented in Figure 44 of the energy expenditures for flights to different planets. The energy expenditures which permit reaching the planets no more than 3 years after launch from a near-Earth orbit are indicated for distant interplanetary flights. It is evident from the diagram that booster rocket units capable of developing a speed of from 3 to 30,000 meters per second and more are needed to investigate the Moon, planets of the terrestrial group, and also Jupiter and Saturn.

The characteristics of the size of spacecraft equipped with various types of motors are cited in Figure 45: liquid rocket motors operating with high energy liquid chemical fuels, nuclear rocket motors, and electric reactive motors.

It is evident from Figure 46 that, independently of the type of onboard motors of a spacecraft, its initial mass in near-Earth orbit increases /167 steadily, reaching several thousand tons.

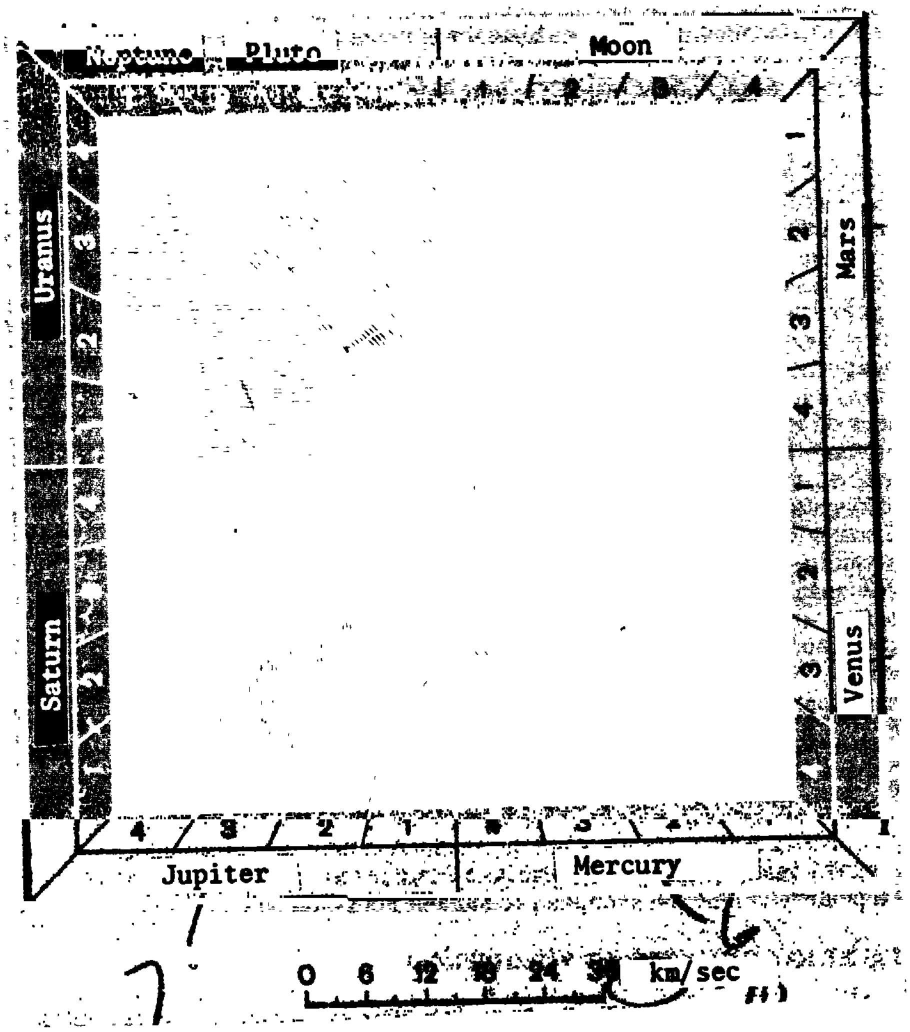

Figure 44. Energy Expenditures for Flights to the Planets of the Solar System: 1, Probes to the Planets; 2, Flyby of the Planets; 3, Flyby with Insertion into Planetocentric Orbit; and 4, an Expedition to the Planets or their Satellites.

Figure 47, in which a comparison is given of the dimensions and masses of spacecraft with one of the most famous buildings in the world, the Ostankinskaya television tower (537 meters), gives a clear notion as to the sizes of the spacecraft which permit the placement into trajectories of the spacecraft whose masses are indicated in Figure 46. Such enormous aggregates in size having colossal mass naturally require power plants almost improbable in their power. This is undoubtedly an exceedingly complicated scientific and engineering proble,. Such aggregates are not only difficult to produce, but what is more important, difficult to operate.

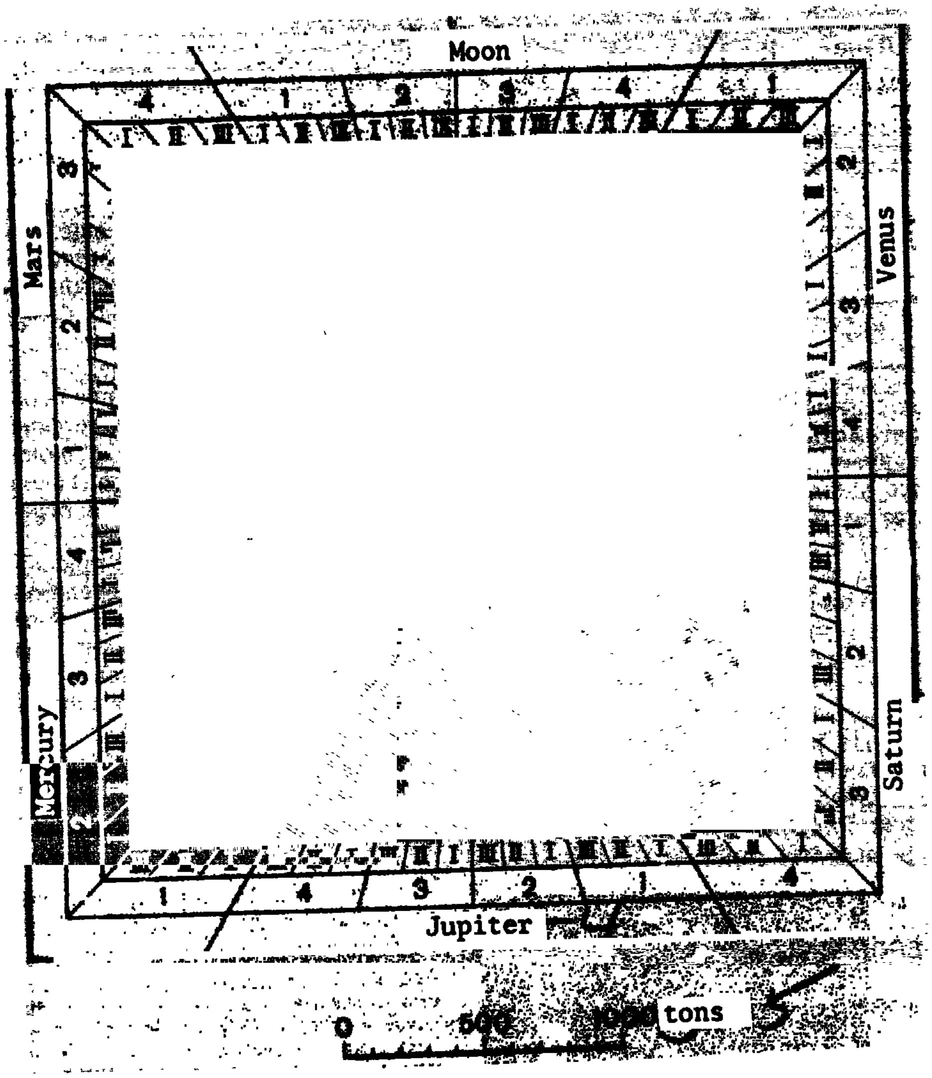

Figure 45. Provisional Characteristics of the Masses of Spacecraft for Investigating the Planets: I, Using Promising Liquid Rocket Motors; II, Using Nuclear Rocket Motors; III, Using Thermoelectric Rocket Motors; I, II, III, IV, Mission Profiles Indicated In Figure 44. The characteristics of spacecraft for solving a number of problems with respect to Venus, Mercury, Jupiter, and Saturn exceed the limits of the diagram.

Space Harbor

"We can easily conquer the Solar System with available technology. Let us first solve the easiest problem: constructing an orbital settlement in the Earth's vicinity as its satellite at a distance of 1-2,000 kilometers from the surface outside the atmosphere... Having settled here permanently and publically, let us obtain a reliable and safe base, familiarizing ourselves well with life in space (in the vacuum); we will already more easily change its velocity, moving away from the Earth and the Sun, and generally wandering where we please."

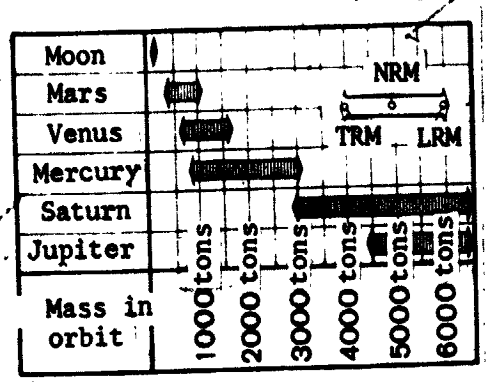

Figure 46. Provisional Mass of Expedition Aggregates for Flights to the Moon, Mars, Venus, Mercury, and Satellites of Saturn and Jupiter. The distribution of the initial mass is obtained by the use of various types of rocket motors (LRM, NRM, and TRM).

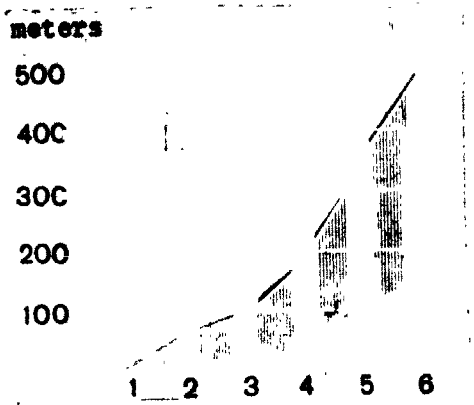

Figure 47. Comparison of the Dimensions and Masses of Promising Booster Rockets with the Ostankinskaya Tower (537 meters). The scatter in the launch masses is due to the use of different types of motors for the booster rocket's stages; the minimum mass corresponds to the use of liquid rocket motors and thermoelectric rocket motors, and the maximum mass corresponds to the use of liquid rocket motors. The overall sizes of the rockets for one and the same task are quite similar. 1, Saturn-5 — 2,700 tons for the Moon; 2, 6,000-30,000 tons for Mars; 3, 10,000-45,000 tons for Venus; 4, 12,000-90,000 tons for Mercury; 5, 45,000-180,000 tons for Saturn; 6, 70,000-250,000 tons for Jupiter.

The pioneer of the celestial paths K. E. Tsiolkovskiy advanced this idea already in 1926 in his classic work "Investigation of the Outer Spaces by Reactive Devices". He assumed that since such an "extraterrestrial island" must have significant dimensions and mass, it must be constructed and tested on Earth and then delivered in parts with the help of payload rockets to the necessary altitude, where cosmonauts would again assemble it into a single structure suitable for an extended stay in it by people and the concentration of the necessary loads. This idea seemed so fruitful that at the present time the majority of interplanetary flight projects are oriented towards it. It is true that, during the first stages of the settlement of space, one should not exclude the possibilities of the construction of an analogous station directly in space from the stages of the rocket aggregates placed in near-Earth orbit (idea of the Soviet scientist A. A. Shternfel'd).

Important problems in this direction have already been solved by Soviet science and technology. One should recall that as early as 1962 the Vostok-3 and Vostok-4 spaceships, manned by the pilot-astronauts Andriyan Nikolayev and Pavel Popovich, who completed the first group flight in the history of cosmonautics cosmonautics, were placed near to each other (5-6 km). Later automatic docking docking was accomplished between the Kosmos-186 and the Kosmos-188 spacecraft, and also the Kosmos-212 and the Kosmos-213 spacecraft. Then on the manned spaceships of the Soyuz type, a system for the rendezvous of two ships, and subsequently the docking of two manned spaceships, was worked out quite well. /168

In the summer of 1971, Soviet scientists established in near-Earth outer space the first long-term Salyut-Soyuz orbital scientific station in the history of the world. This was qualitatively a new step on the path of constructing in near-Earth space large orbital stations for extended operation.

In 1973 the Skylab orbital space laboratory was produced in the USA[17]. All this brings us near the time when it will become possible to construct in near-Earth space large orbital stations. They will permit a significant broadening of the circle of scientific investigations relating to the Earth, its atmosphere, and the outer space belonging to it and will also solve a number of scientific-engineering problems of great national economic significance. Among them one can name such problems as intercontinental radio and television broadcasting, radio communications at ultralong distances, the organization of a universal service of observing solar activity and its effect on the weather, accurate navigation for sea and air vessels, and also for spacecraft directed towards the depths of the Universe. On such stations one could comprehensively investigate the conditions of human activity in outer space and clarify many problems associated with providing for their safety during long stays in flight. Cosmonauts on them would be able to carry out preparation — "acclimatization" — prior to taking off on distant interplanetary flights.

One of the important elements of a large orbital station would be the space shipyard. Its main purpose would be to provide for the assembly of interplanetary ships from construction units on Earth. Liners would be launched from this shipyard for flight to distant worlds; they would moor here after completing their space journey. The conquerors of the spatial wilderness who arrive here would undergo any quarantine that was appropriate, after which they would return to Earth in special transport ships. With such space docks a flight to celestial bodies and back would appear to consist of several separate stages (Figure 48).

First stage — casting off (launch) of the interplanetary ship from the space port and its entry into an interplanetary trajectory (1).

Second stage — flight of the ship along an interplanetary trajectory to the destination planet (2).

Third stage — entry into a near-planetary orbit and flight along it for a certain time (3).

Fourth stage — casting off of a unit from the interplanetary ship and its landing on the planet (4).

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[17]Skylab upon translation into Russian means "celestial laboratory".

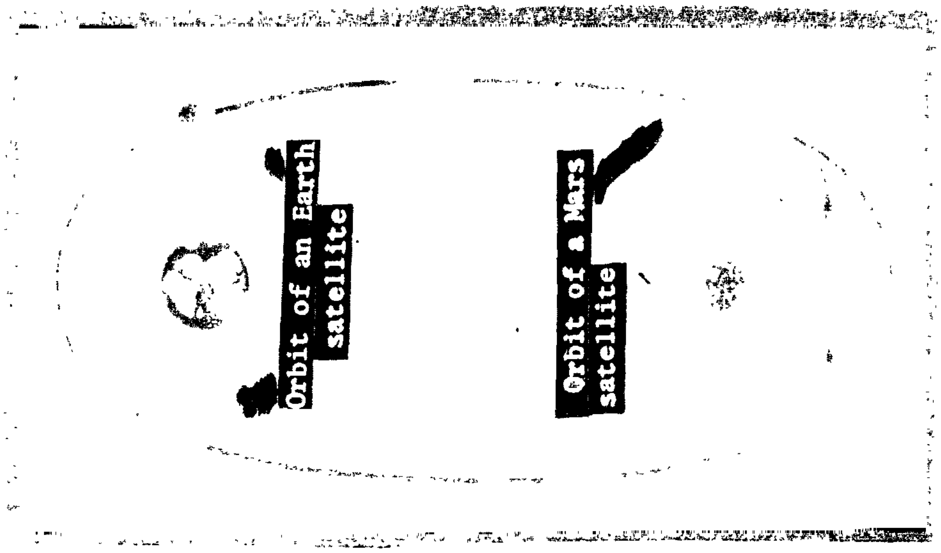

Figure 48. Stages of an Interplanetary Flight. Interplanetary space liners assembled at a near-Earth space station consist of orbital and exploratory units. The acceleration of the ships to the velocity necessary for flight to a planet is carried out by special boosters which return to the launch complex. /169

After the space liner enters a near-planetary orbit (3), part of the crew transfers to the exploratory unit, which is separated from the ship and makes a landing on the surface of the planet being investigated. After carrying out the necessary tasks on the planet, the exploratory group returns to the near-planetary orbit in the ascent stage of the exploration unit and carries out a rendezvous with the orbital unit of the interplanetary ship. The cosmonauts transfers to a flight trajectory back to Earth. Upon returning to the vicinity of the Earth, the ships of the interplanetary expedition approach the orbital terrestrial complex and rendezvous with it.

Fifth stage — ascent stage of the exploration unit takes off from the planet's surface and enters a near-planetary orbit for docking with the interplanetary liner (5). /170

Sixth stage — launch of the interplanetary liner from the near-planetary orbit and its entry into an interplanetary trajectory in the direction of the Earth (6).

Seventh stage — flight of the liner along an interplanetary trajectory and its entry into a near-Earth orbit (7).

Eighth stage — docking of the interplanetary liner at the port of the near-Earth space harbor (8).

Let us briefly discuss the advantages of launching interplanetary space liners from a near-Earth space dock.

Cosmodrome in Orbit

Interplanetary liners, when taking off from a cosmodrome in orbit, in order to overcome the terrestrial attraction, can develop a significantly lower velocity than if it were necessary to takeoff from the Earth, and this means that large fuel supplies will remain onboard (provided, of course, that the fuel tanks are completely filled). The additional velocities, in case the interplanetary cosmodrome station is at an altitude of 200 km, are approximately: 3.6 km/sec for a flight to Mars; 3.5 km.sec — to Venus; 6.3 km/sec — to Jupiter; 5.6 km/sec — to Mercury; and 8.4 km/sec — to Pluto, and an additional velocity of 8.75 km/sec is necessary for the spacecraft to leave the confines of the Solar System.

The second factor which makes the use of an orbital cosmodrome advantageous is the fact that, in this case, one can have a significantly larger useful payload onboard the interplanetary liner than if it were launched from the Earth's surface. This is due to the fact that the useful payload mass depends not only on the velocity which must be imparted to the spacecraft, but also on the direction of its motion with respect to the Earth's surface. A booster rocket which takes off from the Earth's surface can achieve the necessary speed by moving strictly vertically or keeping the direction of its motion close to the horizontal. In the latter case the aerodynamic braking becomes more appreciable. That additional fuel expenditure is required to insert the spacecraft into an interplanetary ship from a space dock almost in the horizontal plane, for which a significantly smaller fuel expenditure is required, and, in connection with this, it is possible to accomodate a larger useful payload on the ship with the same power plant.

If the interplanetary ship is launched from the Earth's surface, scientists must take into account the position of the destination planet relative to the ecliptic plane and its orbital position. This apparently easy problem is transformed in actuality into a very difficult navigation problem because it is necessary for the launch from the Earth to make necessary corrections to the flight trajectory of the booster rocket. And although it is possible to make /171 corrections, nevertheless the trajectory for placing the ship onto its flight path is made more complex, and consequently the possibility of the accumulation of errors is increased. It is possible to avoid them by making the launch from an orbital cosmodrome. In addition, by using a mobile platform revolving around the Earth, we obtain a significantly greater number of positions from which the launch of interplanetary ships is convenient. A launch can be carried out practically above any point of the surface, and therefore the instant of takeoff is not so rigorously restricted by the position of the launch area and the launch time. One can select the launch point and trajectory shape which provide for small gravitational losses. A far greater accuracy of placement into the selected trajectory is provided by launching an interplanetary ship from a near-Earth cosmodrome; in fact, in the case of a launch from the Earth, the rocket must not only move for a certain length of time, rigorously maintaining a specified direction and flight speed, but at the same time can jettison spent stages, turn its engines on and off, and vary their operating modes. It is perfectly understandable that, no matter how sophisticated the automatic control is, there can always be some deviations from the calculated data. These errors, which accumulate during the rocket's movement in the acceleration phase, unavoidably result in a deviation of the actual trajectory from the calculated one. When the spacecraft is launched from an Earth satellite, it is possible to determine with great accuracy the velocity, altitude, and direction of its flight, take deviations into account, and thereby significantly increase the accuracy of the spacecraft's placement into its interplanetary flight path.

An interplanetary ship launched from a near-Earth space station can be accelerated by using nuclear motors since there is no contamination of the lower layers of the Earth's atmosphere by radioactive material. It is also entirely possible to use low-thrust motors for this purpose, i.e., electric rocket motors, or under the conditions of the first cosmic velocity, it is sufficient to apply even an insignificant thrust force to a spacecraft in its weightlessness state, and it will begin to move away from the Earth. This will be most advisable for unmanned (payload) spacecraft since an extended stay by manned ships in the radioactive belts of the Earth would be dangerous to the cosmonauts. The flight conditions in interplanetary space differ very significantly from those for placing spacecraft into a near-Earth orbit. Spacecraft making the flight from the Earth to near-Earth orbit must have a well-streamlined shape since it is necessary for them to overcome atmospheric resistance. Because of their rapid acceleration they must withstand large dynamic loads and experience significant thermal heating of their outer shell; therefore their body must be quite durable. It is not necessary for an interplanetary ship making a flight from the orbit of an Earth satellite to an orbit of the satellites of a celestial body to overcome atmospheric resistance; it can move under far smaller acceleration, and therefore its body can be less /172
durable and perhaps lighter. The selection of the shape for an interplanetary liner will probably be oriented towards minimizing its structural weight while achieving maximum volume, as this will make it possible to accomodate the necessary payload while ensuring complete safety and the necessary comfort for the crew.

As is well known, Soviet scientists, in developing the ideas of K. E. Tsiolkovskiy, were the first to launch an automatic interplanetary station from the orbit of an Earth satellite and thereby confirmed experimentally its advantages. This occurred on February 12, 1961, with the launch of an automatic station to the planet Venus. Since that time all the spacecraft launched toward celestial bodies both by the Soviet Union and by the United States of America have been launched from near-Earth orbits.

Interplanetary Liner

It is similar to a certain extent to a submarine. Just as in the water, a person in airless space cannot survive without special means of life-support. Therefore special hermetic compartments, completely isolated from the external environment, are necessary in an interplanetary liner just as in a submarine. The necessary microclimate must be produced in them artificially: the composition and pressure of the air required for people to breathe and a favorable temperature must be continually maintained, and also all toxic vapors liberated by living organisms and equipment must be absorbed. In order to enhance the ship's reliability and to increase the safety of the crew, the liner is divided into separate hermetic compartments which, if necessary, can be isolated from each other.

One of the barriers which the interplanetary medium presents for man is radiation, which has a destructive effect on living organisms. It comes from galactic cosmic radiation, explosions on the Sun, the radiations of the Earth's radiation belts, and nuclear equipment onboard. The antiradiation protection of the entire shop is designed for the usual average background of cosmic radiation of interplanetary space. And only the hermetic compartments in which the cosmonauts live have the special multi-layer enhanced protection. It is impossible to provide reliable protection for the crew simply by increasing the mass of the special shielding material in the ship's hull. Due to explosions on the Sun or on other stars of the Universe, interplanetary space may be filled with cosmic radiation deadly to people which it is impossible to screen out even in reinforced compartments. Taking this into account, a special refuge, the so-called storm compartment, is provided on the ship. Its size makes it possible to shield all the crew members. It contains the devices which permit a minimum of control over the ship and provides for radio and television communication with Earth and among the ships in the flight, as well as its own, though very small closed ecological[18] system, which provides the crew with all they need to maintain /173
vital activity. After all, it is not known how much time the crew will have to spend in this compartment! In addition, special individual means of shielding are available to the cosmonauts in the form of hermetic mattresses filled with liquid which absorbs the deadly radiation. If needed, various pharmacological preparations are used by crew members which can reduce the effect of cosmic radiation on an organism. Automatic dosiometers keep watch on the ship. They continually check the Sun's condition and notify the crew of a possible worsening of the radiation level.

Interplanetary space is "shot through" from all sides with meteoric material. One can encounter it both as individual fine dust particles or large meteoric objects and meteor streams. They are extended swarms of particles of solid material ranging from several milligrams to hundreds of kilograms in mass. Moving at a speed of 50-70 km/sec, they are capable of penetrating the ship's shell. In order to protect the ship against meteoric objects, its hull must be made multi-layered. When a meteoric particle penetrates the ship's body, its special material momentarily flows, plugs up the opening, and hardens again. Special shields made of highly durable materials are used as an additional passive anti-meteor protection on the ship. They are placed in front and on the sides of the ship at a distance of several hundreds of meters. Similar to umbrellas, they screen the ship, forming a cone-shaped space around it. When a meteoric particle strikes the protective shield's surface, its enormous kinetic energy is changed to a significant extent into thermal energy. This causes it to be heated greatly, and it, along with the material knocked out of the shield, which

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[18]This system is discussed in detail on page 183.

is also heated, will move towards the ship, not as a solid mass, but as an incandescent, rapidly expanding gaseous cloud which, due to the extreme vacuum, rapidly disperses in the space between the shield and the ship. Special high--temperature plasma rays, which are generated onboard the ship, belong to the category of active methods of anti-meteor protection. It is possible by using them to "burn up" (more accurately, to melt) large meteoric objects before they encounter the ship's anti-meteor umbrella.

In case a ship encounters strong magnetic fields (and they occur in outer space), they may have an adverse effect on the cosmonauts. In order to protect them from this, a special anti-magnetic system is provided on the ship.

High-power nuclear engines are used to accelerate the liner to the necessary velocity and to decelerate it upon its entry into a near-planetary orbit, and low thrust electric rocket motors are used to move it in outer space. There /174
is a solar sail on the ship as a reserve method.

The interplanetary ship will not spend a day or a week in flight, but months and years. During all this time its crew must be provided with air, water, and food. It was determined a long time ago that a person, in a hermetic compartment carrying out a specified number of tasks, uses during a day about 800 grams of oxygen, 700 grams of food in the form of necessary amount of proteins, fats, carbohydrates, vitamins, and mineral oils, as well as about 6 liters of water, of which about 2 liters are for drinking, and the rest is intended for personal sanitation needs. If one adds the cubic mass and packing of the food and air products, the mass of everything necessary for a single person comes to about 11 kg per day. Based on this, the supply of these products must, correspondingly, be 48-72 tons for a two- or three-year trip, for example, by a six-man crew. Of course, if one brings everything from the Earth, the takeoff mass of an interplanetary liner will be prohibitively great. In order to provide the cosmonauts with everything necessary for life-support, the liner will be converted into an "island of the Earth" in space, i.e., into a miniature model of it. A biological cycle duplicating that of the Earth, and, by analogy with the latter, called a closed ecological system[19], will be reproduced in special hermetic compartments and greenhouses.

K. E. Tsiolkovskiy as early as 1926 advanced in his paper "An Investigation of Outer Space by Reactive Devices" in the most general form the use of the cycle observed on the Earth as the basis for a model operation in space to obtain oxygen, water, and food. He wrote: "It is not possible to exist for a long time in a rocket: supplies of oxygen for breathing and food must run out soon, and the products of respiration and digestion will foul the air. Special living quarters are necessary — safe, bright, at the desired temperature and with renewable oxygen, and a constant influx of food..." only a closed cycle can eliminate the need for colossal supplies of oxygen, water, and food on the ship.

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[19]Ecology is that area of science which studies the interrelationships of organisms and their environment in natural biological systems (associations of the animal and vegetable worlds).

An extended flight in a state of complete or partial weightlessness has an adverse effect on the human organism. This is explained by the fact that, under terrestrial conditions, a significant fraction of the organism's energy is expended in maintaining in an efficient condition the large muscle mass which permits a person to stand and walk, maintains the skeleton's rigidity, absorbs the weight of the entire organism, and also provides for the normal operation of the cardiovascular system and other organs. This load is removed in weightlessness. /175 And, naturally, a healthy organism then begins to be freed from everything "superfluous" which requires energy. The load of the bone-muscle system and consequently, on some part of the muscle tissue, is decreased, the density of the bones is reduced, and the cardiovascular system undergoes changes. If one does not take protective measures, this unavoidably causes the cosmonauts to reach a state of adynamia, i.e., weakness. Therefore it has been necessary to solve the problem of creating artificial gravity on the ship to make a successful interplanetary flight.

In order to understand the significance of gravity, let us point out that, under terrestrial conditions, when a person walks on the Earth, there are, in addition to the forces whose action he distinctly perceives (for example, the force of gravity, the force of friction, and so on), other forces acting which are so small that he does not notice them. These include the centrifugal and Coriolis forces of inertia which are due to the Earth's rotation.

Let us suppose that the place where a person is standing is not a planet but the inside of a ship. If the ship is rotating about its axis of symmetry, centrifugal force will act on the person and will press him to the floor, just as the force of gravity presses a person to the Earth. But what principle difference is there here? We know that the magnitude of the centrifugal force depends on the radius of rotation. But since the head of a person standing on the "floor" of the ship's cabin is nearer to the axis of rotation than his feet, centrifugal force, which replaces the force of gravity in this case, will increase continuously in the direction from the head to the feet. Therefore it will be more difficult to move the feet than the head and the arms. This difference in the magnitudes of the centrifugal force acting on the head and the feet of a person is called a gravitational gradient. It is not difficult to imagine that, for the same angular velocity, the smaller the radius of rotation, the more appreciable the gradient. If a person is not standing in one place but is walking around the ship, even the Coriolis force of inertia will begin to act on him. And he will certainly feel thus since the ship's angular rotational velocity. And, since the larger the effect of the Coriolis inertial force, the greater the ship's angular rotational velocity, it is impossible to select its magnitude arbitrarily.

Investigations have shown that the upper limit of angular velocity at which disorientation of a person's vestibular apparatus does not occur is 0.4° per second, and that the lower limit is when a person can still move about, if the acceleration due to gravity is no less than 0.28 of the terrestrial acceleration. But if one takes into account the fact that it is necessary for the cosmonauts to move about in the ship and in a direction opposite to its rotation (the Coriolis force will raise it slightly), the lower limit must be increased. Soviet scientists E. M. Yuganov and N. D. Enel'yanov have suggested that the lowest effective value of artificial gravity allowable from the physiological point of view is 0.28-0.3 g. To create this artificial attractive force, a rotational speed of 10°/second is sufficient, and the optimal radius of rotation is 9 meters. The Coriolis acceleration forces, which unavoidably appear when the cosmonaut moves about in the ship's cabin, will not be very large. An interplanetary liner will have the design, shape, and special equipment which provide the members of its crew with conditions so that they can stay at different degrees of gravity, from the minimum up to the terrestrial value. /176

Weightlessness makes it harder to maintain necessary temperature conditions in the ship. Under terrestrial conditions the temperatures are mixed due to air convection. Cold, "heavier" air, falls, and warm, "lighter" air, takes its place. But where there is no weight, there is no "heavy" or "light" air, and perhaps convection does not occur. In order to produce it, special ventilators are installed everywhere in the ship's rooms. The temperature regulation system provides for the necessary air circulation in the ship's compartments.

A necessary attribute of an interplanetary liner is special descent craft. After all the liner, as it approaches, for example, Mars, has a very significant mass, due to the large supplies of fuel necessary for the return flight, the powerful rocket motors, the closed ecological system, and other special equipment. It is not necessary to land all this payload on the planet since all of this is needed to reach the interplanetary flight path for the return to Earth. But this is not the only cause. To land a heavy and cumbersome ship on another planet is not simple, and through a planetary stmosphere it is not possible at all since the shape of the interplanetary liner does not satisfy the requirements of aerodynamics.

The descent craft, which has a far smaller mass, overall dimensions, and the proper shape, is far easier to land on the planet. It is a complex two-stage design. Its first stage is used for landing on the planet, and the second stage is used for the takeoff from it and to enter into a near-planetary orbit to dock with the interplanetary liner. A special mobile device — a planetokhod [Translator's Note: planetary rover — American equivalent] — is on each such descent craft. The cosmonauts will use them to travel over the planet's surface.

Crew of an Interplanetary Ship

Three Soviet men were the first multiple crew in the world on the spaceship Voskhod: the ship's commander V. M. Komarov, his scientific co-worker K. P. Feoktistov, and surgeon B. B. Egorov. Precisely why was this troika so constituted? This was stipulated by the goal-oriented tasks and technological capabilities of the spaceship.

The staffing of a crew of an interplanetary liner is a problem of incomparably greater complexity. One of the main questions which arises here is determining the number of crewmen. The solution to this problem is directly dependent on the closed ecological system can support which must provide the crew with life-support. This exceedingly important circumstance causes a rigorous restriction of the number of crewmen possible. But staffing the crew /177 of an interplanetary liner is not determined just by this. Such factors as psychological, biological, and professional compatibility have enormous significance.

Imagine two close friends who understand each other and what is being said from half a word, a single glance, or a shrug. Each of them strives to make things as pleasant as possible for the other when doing this or the other task. They usually say about such friends: "they would go through fire and water for each other." Psychologists call such people compatible from the psychological point of view.

A characteristic of another kind — biological compatibility — is very important due to the fact that a collective flight introduces its own complexities into the creation of an acceptable atmosphere in the spaceship's hermetic cabins. After all each member of the crew, crudely speaking, creates his own living environment since a person has an individual specific microflora. Microorganisms harmless to their host are found under normal conditions on the outer skin of a person, on the mucus linings of the upper respiratory tracts, and in the digestive tract. These are the so-called saprophytic microbes. But they can have an adverse effect on other members of the crew. In numerous experiments carried out in hermetic rooms, it has been established that the amount of microorganisms residing on the skin and the mucus linings of a person increases noticeably and is maintained at a level which exceeds by several times the usual levels. As a result, microorganisms accumulated in significant amounts in the air of inhabited rooms. And it is well known that the "relationships" between microorganisms can be antagonistic. This can lead to undesirable consequences since an increase in the microbial contamination of the air of a hermetic room will facilitate the onset of illnesses. This is one aspect of biological compatibility. The other, no less important characteristic of the fact that individual differences in people's metabolism[20] are reflected in the qualitative and quantitative composition of airborne impurities liberated during respiration and from the surface of the skin. Thus, for example, the specific odor of the respiration products or the outer skin of one person may cause an adverse effect on another. Therefore the choice of identical personalities, while taking into account their biological compatibility, has /178 exceedingly great significance.

The crew of an interplanetary liner is not the arithmetic sum of the individuals, but it is a unique association which must function in a harmonious and concentrated manner under the very narrow conditions of spaceflight. And in that case the nature of the people's vital activity on the ship will differ very significantly from that on Earth. After all in spaceflight, a person is confronted with a number of sharply defined factors with which he has never been confronted under the conditions of this terrestrial existence. They can be separated arbitrarily into three groups.

The first group includes factors associated with the ship's flight dynamics: overloads, vibration, and noise when the ship takes off and descends as well as the weightlessness during flight with the engines off.

The second group is associated with the conditions characterizing outer space as a unique environment for people, namely: the vacuum of the medium surrounding the ship; the presence of very intense ultraviolet and cosmic radiation harmful to living organisms; and the possibility of the ship and the crew being affected of meteoric material, as this can result in the penetration of the ship's body, the dehermetization of the living compartment, and injury to its inhabitants.

The third group includes factors caused by the cosmonaut's extended stay in the artificial conditions produced on the ship, as well as by their complete isolation from the external environment and the limitation of their living space. This group includes factors associated with the conditions of the cosmonaut's work and relaxation, the alteration in their biological rhythm, and the peculiarities of the preparation and ingestion of food and water, as well as the performance of the bodily functions.

All these distinctive characteristics of spaceflight require not only comprehensive professional training on the part of the crew members, but an exceedingly high degree of mental stability. After all they must not only live together but work together in a very well-coordinated fashion. Good mutual relationships are indispensable for this. The irritability of one crew member, the hot temper of another, or unjustified stubbornness can cause alienation, conflicts, and contrariness, and this will certainly affect the completion of the planned flight program.

There can be as small resentments, irritability, or bad character in the crew of a spaceship. Extended spaceflight is the most serious test of an individual's entire psyche, and only people strong in spirit, cheerful, and totally devoted on their work can withstand it. The egotist, the self-lover, cannot be in such a situation. He does not help to create the most favorable conditions on the ship... G. S. Titov has written about this.

All the members of the crew must be attentive to each other and mutually solicitous. An indispensable quality must be their mutual respect and willingness to spring to a comrade's aid at any time, especially in dire or critical situations.

An exceedingly important trait for any crew member of a spaceship is courage. It permits him to overcome the feeling of fear caused by an extended separation from the Earth. It is true that a feeling of fear can arise in any person since he is a highly-developed biological creature. The question is only whether various people will give different forms of expression to this or that occurrence. Some people's feeling of fear may cause confusion and panic. Other people, on the contrary, do not lose their self-control. One should not forget that each person has his own tendencies and habits, which people exhibit in different ways in different situations. It is well-known that the inner world of a person's psychic processes is extremely complex and multi-faceted. It includes volitional and emotional processes, peculiarities of character and temperament, a person's capabilities, knowledhe, habits, customs, and beliefs. It is also understood that the nature of a person's actions is very complex and at times difficult to explain.

The history of scientific expeditions gives many sad cases of the alienation caused by a feeling of fear in the face of the unknown. In this respect the story of the famed Arctic investigator Norwegian scientist Fridtjof Nansen is quite enlightening. Having drifted in his ship "Fram" as far as the 84th parallel of north latitude, Nansen together with his companion Johansen, set off on skis for the North Pole. When they reached latitude 86°14' and understood that further advance was useless, they turned southward. Almost one-half year later they reached Franz Joseph Land. They walked through configurations of ice and polynia [Translator's Note: dictionary says this means unfrozen patch of water in the midst of ice] in frozen clothing, and they ate dried fish, walrus meat and bear meat. Using the heat of their bodies, they warmed up snow in their water bottles for drinking. But the most difficult thing they had to live through was personal communication with one another. They addressed one another very rarely, sometimes only once a week, but these communications were of an official nature. Johansen, for example, called Nansen "Mr. Expedition Leader," and Nansen called Johansen "Mr. Chief Navigation Officer".

However, in contrast to this situation, many cases are known in which the difficult conditions into which a group of individuals has fallen solidifies the group. Thus, for example, at the beginning of 1960 during a storm in the Pacific Ocean off the coast of the Kuriles Islands, a self-propelled barge was driven out to sea; onboard were 4 Soviet soldiers — Askhat Ziganshin, Philip Poplavskiy, Anatoliy Kryuchkovskiy, and Ivan Fedotov. After 49 days of drifting, they were picked up by American aircraft and taken to San Francisco (USA). While adrift they encountered many critical situations, but they overcame them with fortitude and emerged the victors. The foreign journalists who gathered to interview them were amazed most of all by the solidarity of this small group of Soviet people. Here is a small excerpt of one of the interviews.

Journalist: I know that under such a circumstance it is possible to lose /180
one's humanity, go out of one's mind, and be turned ir [illegible] animals. You had, of course, quarrels, perhaps, even flights over a last c[illegible] of bread or last swallow of water?

Ziganshin: During the entire 49 days the members of the crew did not even say one angry word to one another, When the fresh water appeared to be running out, each received half a glass a day. An no one took an extra swallow. Only when we celebrated the birthday of Anatoliy Kryuchkovskiy did we offer him a double portion of water, but he refused.

Journalist: Did you remember in this hell the birthday of your comrade? And did you not think about death, Mr. Ziganshin?

Ziganshin: No, we did not, we are too young to give up easily.

Journalist: How did you pass the long nights? For example, you, Mr. Poplavskiy?

Poplavskiy: We sharpened fish hooks, cut spoon baits out of a tin can, untangled ropes, and tied fishing line. Askhat Viganshin repaired the signal lamp. Sometimes I read a book aloud.

Journalist: What was the name of this book?

Poplavskiy: Jack London's "Martin Eden."

Journalist: Incredible.

Fedotov: Sometimes Philipp played the concertina and we sang.

Journalist: Show me this historic concertina.

Fedotov: Unfortunately, we ate it.

Journalist: What? How did you eat it?!

Fedotov: Very simple. Parts of it were made of leather. We took it apart, cut it up into pieces, and boiled them in the salty seawater. The leather seemed to be sheep leather, and we joked that we had two kinds of meat: the first kind — leather from the concertina, and the second kind — leather from our shoes.

Journalist: And you had the strength to joke? This is incredible! And do you know what kind of people you are!?

Ziganshin: Ordinary Soviet people!

Yes, Soviet! And one must say that behind this brief reply stood the deepest sense of our social relationships. Soviet people are collectivists in spirit. The principle of the Communist morality — one for all, all for one — is an immutable moral law. From earliest childhood, by absorbing Communist morality, the Soviet people place social interests immeasurably higher than personal ones, and this helps them in many respects to overcome any difficulties and to attain their broad goals. A person in a collective body is an outstanding figure. A comparison is easier: he is a link in a chain. Take out one link, and another one — and there is no tightly unit friendly group. The experience of life is proof that those groups which are bound not only by a general purpose, but by mutual sympathies and a feeling of comradeship, most efficiently dispose of any tasks posed to them. Such groups are psychologically compatible. They are distinguished not only by uniform emotional reactions and behavior, but by the ability (which is very important!) to equalize and soften within the group any individual habits, tastes, and interests which are unacceptable to the majority of the members. In addition, consciousness of the importance of the task entrusted to each member of the crew and to the crew as a whole, and an understanding of the fact that it is impossible to resolve it other than by their combined efforts, promotes not only solidary among the members of the crew but mutual comradely aid, right up to self-sacrifice. Mutual harmony among members of a group is not confined just to willingness to help one another. Members of the crew of an interplanetary ship must possess an exceptionally important trait which is referred to in the language of psychologists as conformity. It means essentially that a person knows how, if necessary, to act just as everyone else does.

But the problem of compatibility among the crew members is not limited just to psychological and biological factors. The professional training of each crew member and the group as a whole is no less important. The volume of work increases significantly in an interplanetary flight, and its diverse nature increases, and this requires that each cosmonaut master several professions. Therefore one can distribute the duties, for example, among 6 crew members, by creating two duty shifts. The ship's commander and his deputy navigation officer command the ship by turns. The surgeon and the biologist ensure the normal operation of the ecological system and check the medical-biological environment in the living compartments of the ship, and the health of the crew members. The task of preparing food and observing the eating habits of the cosmonauts is enstrusted to them. The flight engineer and his assistant ensure the normal functioning of the very complex systems of the different instrumentations. Of course, all the processes on a ship will be automated. And in case of an malfunctioning of an automatic system, an alarm signal will immediately sound and, if necessary and possible, they will switch the reserve unit into operation. But the cosmonauts should not expect such an alarm signal. Their main task consists of seeing that this signal does not sound even once during the entire flight.

The necessity of having on the expedition's staff different specialists requires additional training for the cosmonauts. Thus in the case of a landing on a planet, the surgeons and biologists must know how to carry out a microbiological investigation of the landing site and also carry out observations and investigations of the local flora and fauna. Such specific tasks as meteorology, geodesy, cartography, planetology, astrophysics, and others are entrusted to the engineers. Prior to the most complicated and crucial stages of the flight (light, for example, in case of a landing on a planet or a takeoff from it), the crew members must know how to carry out the complex checking of all the main systems. In essence the ship's crew must assume the analytic functions of the /182 operation and the preventive maintenance of the onboard systems which are carried out by the highly qualified engineering and technical staff of the ground-based service. Therefore the crew members must in addition to their own professional responsibilities, excellent knowledge, skills, and the ability to operate the varied and complicated systems of the ship.

Life on an Interplanetary Liner

We already know that outer space is an environment which differs sharply from the one with which a person is confronted in everyday life. The fact is that the nature of people's vital activity on a spaceship differs very significantly from that on Earth.

Life has existed on the Earth for billions of years. It arose and is maintained due to solar energy and vegetation. The greatest miracle of nature — photosynthesis — takes place in the cells of plants under the beneficient rays of the Sun. Plants, which absorb carbon dioxide gas from the surrounding medium, liberate in the photosynthetic process oxygen and convert inorganic matter (mineral salts, carbon dioxide gas and water) into a complex organic mass saturated with energy which is used by human organisms as food. The greatest role of plants is precisely this! The great Russian naturalist K. A.

Timiryazev described very graphically how this complex interaction of plants with the Sun occurs. In his book "The Sun, Life, and Chlorophyl" he wrote that once, somewhere on the Earth, a ray from the Sun fell, not on barren soil, but on the green blade of a wheat shoot, or, it is better to say, on a chlorophyl seed. In striking, it died out, ceased to be light, but did not disappear. It was only expended for internal work; it cut and tore asunder the bond between the particles of carbon and oxygen, which were combined in carbon dioxide. The freed carbon, combining with water, formed starch. This starch, after conversion into soluble sugar, is finally deposited after a long journey through the plant in the seed as a starch or gluten. It entered in this or the other form into the composition of bread, which served as food. It was transformed into our muscles and into our nerves. And now here are the atoms of carbon in our organisms striving again to be combined with oxygen, which the blood carries to all the extremities of our bodies. The rays of the Sun concealed in them in the form of a chemical stress again take the form of definite force. These rays of the Sun heat us up. They bring us into motion. Perhaps at this minute it plays in our brain...

We have briefly indicated in the chapter "Interplanetary Liner" that, in order to provide the cosmonauts with oxygen, water and food on their ship, a closed ecological system should be created as a miniature model of the Earth and figuratively called a "factory of life in space". Taking into account its exceptional importance on an interplanetary liner, it is advisable to dwell in somewhat more detail on a discussion of this question.

The closed ecological system of the ship includes 3 basic elements: /183
synthesis, composition, and utilization. In the first element plants synthesize organic materials by means of binding, using solar energy, water, carbon dioxide, and mineral salts and converting them into a complex saturated organic mass suitable as food for the inhabitants of the interplanetary liner — people and animals, which comprise the second element of consumption. The third element converts the food materials used by man and animals into an inorganic form suitable for recycling by the plant.

Just as on the Earth, plants occupy the most important place in the shipboard ecological system. These are common especially fruitful and useful higher plants — plants — vegetable crops which are richest in carbohydrates: onion, fennel, watercress, borrage, [Translator's Note: one unknown word] cabbage, rootcrops, and tuber-bearing plants. All of these are cultivated by hydroaeration and aeroponics[21]. Mainly perennial plants are cultivated in the space greenhouse. A harvest is continually reaped from them. This is achieved because the proper illumination and nourishment conditions are created for the plants.

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[21]Hydroaeration is the injection of a nutrient solution and moisture together with air into a soil substrate — an artificial substitute for soil.

Aeroponics means that the roots of the plants are developed in an air environment and only regularly watered by a nutrient solution dispersed by a special sprayer.

Biological and technical characteristics such as maximum productivity per unit volume of greenhouse, high nutritional value, biological compatibility, efficient utilization of light energy, a broad temperature range for development, etc., were taken into account in selecting the crop of plants.

Single-cell microorganisms such as Chlorella and Spirillum algae occupy a special place in the ecological system. Chlorella is a fresh-water green algae. One liter of a suspension of it yields each day up to 10 liters of oxygen. But this is not the only achievement of algae. They are simple, they make it possible to attain a relatively constant rate of accumulation of organic material, and they multiply amazingly rapidly since they have a short vegetative season and a large number of individuals at various stages of development. These algae use up to 10% of solar energy, while the majority of terrestrial plants utilize less than 1%. Algae possess unusual nutritional properties. Chlorella, for example, consists of over 50% valuable protein and has 25% fats, 15% carbohydrates, and 10% mineral salts. It contains 100 times more vitamin C, and 500 times more vitamin A than milk. It also contains 10 amino acids vital to a living organism.

Not only Chlorella, but zooplankton — small animals such as Daphnia, Cyclops, Ortemia, and others — are cultivated in a special pool on the ship. They are the same as in their nutritional properties. Besides zooplankton, deep-water fish live here, such as the mirror carp and the silver carp. They use comparatively little oxygen, and their gill apparatus is suitable for filtration of plankton. This type of fish attains large sizes, and consequently, large weight in a comparatively short time and has numerous offspring. Small animals such as chickens and rabbits are an indispensable element in the ecological system. Since they mature rapidly and can quickly generate offspring, they completely satisfy the need of the cosmonauts for products of animal origin. Microorganisms (bacteria, fungi, protozoa, and others) have a great significance in a closed cycle of materials. They process the metabolic products generated by people and animals.

Let us briefly discuss the operation of the system as a whole.

As is well-known, a person generates on the average 900 grams of carbon dioixde gas and about 1.5 kg of solid and liquid wastes per day from his own vital activity. We direct the carbon dioxide gas immediately into the plant section, both higher (vegetable crops) and lower (crops of various algae). This section has been named the autotrophic organism section. They possess amazing properties: they live, eat, grow, and reproduce, absorbing from their environment carbon dioxide gas, mineral salts, and water, using light energy. This process is called photosynthesis and is accompanied the liberation of oxygen and the formation of organic material, mainly carbohydrates and vitamins. Up to 35 liters of oxygen can be obtained from a single square meter of a space greenhouse, and up to 50 liters of oxygen can be obtained from a one-meter suspension with Chlorella algae. Vegetable products from the greenhouse and the reactor with algae can be converted into food in the space kitchen after the proper processing operations have been performed.

However, the vegetable food thus obtained, although rich in carbohydrates and especially in vitamins, cannot be regarded as complete, because a person still needs animal food. Therefore naturally the introduction into the biological-technological system of animals which, eating the scraps of the higher plants not assimilable by a person (tops, roots, and so forth) and algae, would give crew members food of animal origin. It is completely understandable that this section be connected to the plant section, obtaining from it food and oxygen and giving up carbon dioxide to it.

Solutions of mineral salts in which such elements as nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, and others must be present are necessary for feeding the plants themselves. Such solutions are obtained in the area of utilization or mineralization of the wastes of the vital activity of man and the biocomplex. All kinds of solid and liquid wastes formed in the interplanetary liner go into it. In their composition these wastes (feces, urine, remains of plants and animals, etc.) are mainly organic compounds, and therefore it is necessary to convert them into a form acceptable to plants, i.e., /185 to mineralize them. It is possible to do this by various physical methods (burning, oxidizing) or by biological methods (reprocessing with the help of various useful microorganisms). Biological mineralization of organic materials is a complex, multi-step process. Here several systematically varying functional groups of microorganisms with a very narrow "specialization" in exchanging materials participate within the limits of each step of the transformations of mineralized material. Solutions of mineral salts vital to the plants are obtained as a result of the functioning of this section. Let us add to this the fact that the ship's ecological system includes many instruments, devices, aubassembiies, and equipment for automation, recording, correction, and control, and also for carrying out the complex biological, physical, and chemical processes.

Thus the ship's crew is provided with oxygen and food. The necessary amount of drinking and personal sanitation water is obtained by regenerating it from the liquid wastes of the crew members vital activity, but mainly from the moisture which is evaporated by the plants, and then, cooling off, is condensed.

It is evident even from this brief description that the creation on the ship of a closed ecological system is a problem of exceptional difficulty. It embraces almost all disciplines of natural science. Therefore, in developing it, comprehensive thorough, and complex investigations were required of such fundamental conditions of the existence of terrestrial life forms as the intensity and spectral composition of solar radiation and the background of ionizing radiation, the amount of gravitation, the intensity of the electromagnetic field, the duration of the vital activity rhythms of organisms, and other conditions. In fact the maintenance of a terrestrial value for these factors in spaceflight might not always be possible or even advisable. Therefore it was necessary to carry out many experiments on Earth and in space before it became possible to solve finally this most complex problem in the scientific and engineering-technological sense. Without getting into the technological details of the creation of the ecological system, let us note only some traits which distinguish it from the terrestrial cycles of materials in order to get some notion of the exceptional difficulty of the task.

The complexity is due in the first place to the fact that conversion rates of materials in various biological elements are unequal, and the accumulation of intermediate, mainly gaseous compounds in dangerous quantities and concentrations is possible during the decomposition of these materials.

Therefore it was necessary to overcome great difficulties in solving the problem of maintaining biological equilibrium between the activities of the animal and plant world. As is well-known, on Earth this equilibrium was arrived at spontaneously during the evolution of life. The temporary stagnation of an organic material in one of the biological chains is not appreciable under terrestrial conditions in the overall course of the terrestrial "circle of life" since it is compensated for by the enormous amount of materials and elements which are formed by the accompanying geological and geochemical processes taking /186 place in the water, soil, atmosphere, etc.

Another factor is the tiny value of the interplanetary liner in comparison with the Earth. Here the smallest delay in the cycle can cause the disruption of functions, and the discontinuation of the activity of one of the elements can cause the depletion of the entire system and, as a result, the destruction of the entire animal-plant community. Imagine that for some reason or other algae began to grow slowly. This would mean that immediately less oxygen and biomass would be liberated, and it is well-known that destruction of an individual element of a system disrupts equilibrium more, the greater the fraction this element constitutes of the overall amount of materials processed.

Under terrestrial conditions processes occur extremely slowly, and the volume and space of the Earth's biosphere does a good job of eliminating possible deviations in the operation of the elements in the cycling system. There is none of this in a spaceship: therefore the operations of all the elements in the ship's ecological system are stabilized with regard to the rate of material exchange.

The relationship in the Earth's biosphere between plants and animals is one thing, and quite another in a ship. Here, then, a great danger lurks. Terrestrial plants renew atmospheric oxygen only every 4 years; everything moves infinitely more rapidly on the ship. It is completely obvious that the less the specific amount of material in the system is (per single individual), the higher the utilization rate and the completeness of the processing of materials during each cycle are, the stiffer the requirements on the system's dynamical stability are, and the fewer are the conditions which satisfy these requirements.

Terrestrial microorganisms have been adapted after millions of years of evolution to the alternation of the seasons and the regular succession of day and night. Nature has produced unique "biological clocks" which control many important processes in the development of the fauna and flora of our planet. Thus plants know by themselves when to shed their foliage, and animals instinctively know when to go into hibernation, wake up, or moult. Light rhythm strongly influence man, whose organism is an exceptionally important link in the ecological chain.

The plant and animal worlds of the Earth have adapted to a constant level of gravitational force. Man's skeleton, animal's bones, and plant tissues have been designed for it. A state of complete or partial weightlessness undoubtedly affects the vital activities of the animal and plant worlds.

Based on the number of elements included and the specific amount of participating compounds, both biological and geochemical, the Earth's cycle is sharply different from such a cycle under the conditions on a spaceship. The Earth's atmosphere reliably protects people and animals from cosmic radiation. The air itself in a spaceship may, under the influence of radiation, alter its own physico-chemical properties. This can have a very adverse effect on the ship's inhabitants.

We have already said that on Earth the equilibrium system of the cycle was /187 composed elementally. It would be necessary to create this equilbrium artificially on an interplanetary liner. It would be necessary first of all to arrive at a point where the tempo of the plant's vital processes corresponded exactly to the vital activity rhythm of people and animals. In order to solve this problem successfully, it has become necessary to develop methods to provide for the automatic maintenance of a unique cycle in which the amount of oxygen absorbed by people and animals and carbon dioxide gas liberated by them corresponds exactly to the amount of carbon dioxide gas absorbed by the plants and the oxygen liberated by them. The requirement of the organic materials at a specific time should not exceed their growth, and vice versa. Due to such a rigorously regulated process of cycling of materials, the well-designed process of photosynthesis by green plants, and the regulation of the growth process in individual elements of the system, it would be completely possible to provide for the expedition's members all that is necessary for an extended interplanetary trip.

The specific characteristic of a closed ecological system on the ship (the nonobservance of the similarity conditions and the possibility of man's correcting intervention) make it qualitatively different from the natural model. Therefore, in creating this system on a ship, scientists would not be able to copy the natural cycles of material observed on the Earth, but they would create an original system not having exactly analogous to nature.

The wise men of antiquity said: "Air is the pasture of life." We are accustomed to the fact that 78% of the Earth's air is nitrogen. Therefore it would be completely logical to assume that an artificial atmosphere on a spaceship should be precisely the same. However, in creating the gaseous environment on it, physicians have concluded that it is more advisable from the physiological and technological point of view to use helium instead of nitrogen. It is significantly lighter than nitrogen, does not burn, and is not absorbed by an organism's fatty tissues and blood. An oxygen-helium atmosphere makes it possible to decrease the maximum pressure in the inhabited compartments by a factor of almost 2. This is very important in the event of a sudden pressure differential and the urgent rehermetization of the inhabited compartments required. In fact in this case, the danger of decompression disorders for the cosmonauts and of "poisoning" by the nitrogen dissolved in their blood decreases. If released in the form of bubbles, it can plug the blood vessels, i.e., what happens to divers who rapidly ascend from the depths of the sea to the surface. Imagine that the hermetic cabin was penetrated by a meteor. The air would instantaneously rush out of it. The pressure would begin to decrease rapidly. The bigger the opening and the greater the difference between the initial pressure in the cabin and onboard the ship, the greater the speed with which this so-called "explosive decompression" occurs, and the more dangerous its effect on the ship's inhabitants. Helium is important in that it prevents a harmful reaction on the cosmonauts from induced radioactivity, which occurs /188 under the influence of cosmic radiation on nitrogen molecules. Due to its high thermal conductivity, a helium environment significantly alters a person's heat exchange. Thus while in the usual terrestrial atmosphere, a "comfortable" temperature is 18-24°C, in a helium atmosphere it would be 24-28°C in the daytime, and 26-29°C at night during sleep. This is very important for extended flights, in the course of which release excess heat is slowed. Therefore a helium atmosphere makes it possible to decrease the dimensions and weight of the necessary heat exchangers. It is true that a helium environment alters greatly the spectrum of speech by almost an octave toward the higher frequencies.

This is explained by the fact that a helium mixture has a lower density than air, sound travels through it more rapidly, and a person's speech is distorted.

During the entire flight a monotonous picture is presented to the gaze of the cosmonauts looking out into the abyss of space. In one porthole they see only bright untwinkling stars against a bluish-black sky, and in the other portholes they see the dazzling firey disk of the non-setting Sun. Regardless of the fact that the ship is moving at enormous speed, everything appears to the cosmonauts as if it were congealed. This is explained not only by their relatively slow flight velocity in comparison to the stars, but also by the absence of characteristic orientations in outer space.

There is neither day nor night, summer nor winter on the ship (of course, natural ones like on Earth). The cosmonauts do not smell the odors of morning freshness nor hear the sound of rain... Nevertheless, the cosmonauts sense an accustomed environment in the ship's inhabited compartments. It reminds them of the everyday and the beautiful which they temporarily left behind on the Earth. The ship's creators have devoted much attention to interior decoration — coloring, illumination, arrangement of working places, equipment, and rest and recreation areas. There is not a single detail of shape, color, and arrangement in the outfitting of the hermetic compartments which would not be thought over intensely by the engineers, physician-physiologist, psychologists, and other specialists. There is not a single sharp angle; everything is smoothly rounded and has soft upholstery. Instruments of various kinds and equipment are arranged so that the crew members do not have to expend much energy and attention to find the necessary knob, level, or scale.

One of the remarkable characteristics of the living compartments are the ventilators. There are many of them everywhere. Why are they necessary? Under normal terrestrial conditions the exchange of air in a closed room occurs through thermal convection; hot air becomes lighter and rises, and new cold air takes its place.

There is no convection in weightlessness. Therefore the air on the ship is shifted by force. The ventilators solve this problem. With their help heat is carried away from the heated housekeeping instruments and equipment.

A varied order for the day has been established for the ship's crew members: /189 each crew member devotes 4 hours to operational duties, actively relaxes for 4 hours, and sleeps for 4 hours. During the active relaxation the crew members occupy themselves with special exercises, eat, read, listen to music, watch movies and television broadcasts from the Earth, analyze and summarize scientifix data, etc. It is specified in the schedule that all the cosmonauts not asleep or, at least, the majority of them, sit at the table together. In factm eating is not simply the ingestion of food, but a very complex process in which physiological, psychological, emotional, and other fundamental functions are closely associated.

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You, the reader, can now conclude from everything that has been said in this book what is the purpose and complexity of solving the problems of interplanetary communications.

But there is no doubt thatm whatever difficulties stand on this path, mankind having plowed the first furrows in the virgin soil of outer space, will with time transform them into broad highways joining the Earth to other worlds.

Years will pass... Centuries... The boundary of the unknown will be pushed further and further into the Universe. New star planes will criss-cross interplanetary and interstellar space. But the unparalleled exploits of the Soviet people, who carved for mankind a path into his shining future — into Communism — and opened up the way to the stars, will remain in mankind's memory forever. These great achievements will never fade before any new heroic achievements of mankind. On the contrary, the greater the triumphs of mankind on the path of mastering the boundless spaces of the Universe, the brighter will shine in civilization's firmament the dawn of the space era, of which we, dear reader, are the contemporaties and creators.

In conclusion we would like to turn your attention to two very important matters directly related to future space achievements.

Obviously space travelers in the first interplanetary flights will be approximately in the same position in which the first explorers of our planet were in their time. Severe gales and storms, ocean currents and submarine reefs, vagueness of the conditions ahead, and other dangers of distant sea journeys can be compared with the considerably greater dangers of an interplanetary journey: an encounter with meteor strems, sudden explosions on the Sun when interplanetary space is filled with radiation lethal to living organisms, crossing the strengthened radiation belts of celestial bodies, and an encounter with other unforeseen, but very dangerous, space phenomena — large meteoric objects, asteroids, and comets. This, and also the very prolonged stay of the investigators in interplanetary flight, figured in years, requires a special /190 design of interplanetary liners which carry a crew and very significant supplies of fuel, rations, and scientific and auxiliary instrumentation. Of course, it is impossible to arrange all of this on a single ship. Therefore it becomes necessary to use several ships. It is appropriate here to draw a certain analogy with the journeys of Columbus, Magellan, and other early explorers of our planet. Columbus would probably not have discovered America if he had set sail on a lengthy sea journey with not 3 but with a single caravelle. And the expedition commanded by Magellan would not have completed the first circumnavigation of he had not had 5 ships. As is well known, only one ship returned home from each of these expeditions, and the remaining ships went out of operation for various reasons.

The presence of several ships in the composition of an expedition carrying out an interplanetary flight makes it possible not only to distribute the necessary instrumentation but will create for the expedition's members the desirable comfortable conditions and will greatly increase the possibility for the successful accomplishment of the interplanetary journey.

However, the creation of interplanetary liners and the preparation and carrying out of interplanetary expeditions is a problem of exceptional scientific and technological complexity. Such undertakings require not only enormous material expenditures but also enormous intellectual effort on the part of those who execute them. The challenge which we have flung out to outer space today has no equal in the history of civilization. In the continual striving for knowledge of the world around us, no other goal can so irresistibly summon all peoples and all nations to join together in a single creative rush to solve these enormous problems. Therefore it is natural that, if the whole world combined its efforts not only in the scientific sense, but also with respect to material expenditures, this would greatly accelerate the investigation and mastering of outer space and the celestial bodies of the Solar System. There is undoubtedly a real necessity for this.

"...Mankind — write the founders of scientific Communism K. Marx and F. Engels," - always sets before itself only those problems which it can solve since it always turns out, on the closest inspection, that the problem itself arises only when the material conditions for its solution are already present, or are in the making." (K. Marx and F. Engels, Soch. [Works], 2nd edition, Volume 13, p. 7).

All the necessary means are in the arsenal of contemporary science and technology for the successful solution of such majestic problems — powerful space rocket technology, atomic and solar energy, the means of remote radio control and automatic electronic control, and much else. The problem facing the governments and peoples of all countries of the world is to use these great discoveries of mankind's genius for the further progress of science and technology for the good of all mankind.